23. *The* Secondary Rocks *of* Scotland. Second Paper*. *On the* Ancient Volcanoes *of the* Highlands *and the* Relations *of their* Products *to the* Mesozoic Strata. By John W. Judd, Esq., F.G.S. (Read January 21, 1874.)

[Plates XXII. & XXIII.]

Contents.

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* In the first published paper of this series (*vide* Quart. Journ. Geol. Scc. vol. xxix. p. 97) I found it possible, in a single communication, not only to discuss the nature and origin of the remarkable physical relations of the vestiges of the Secondary strata on the east coast of Scotland, but also to reconstruct from them the history of the several Mesozoic periods as exemplified in that district. This, however, was only accomplished by extending the paper to a somewhat unusual length; and in dealing with the strata of the same age on the western coast, I have found it impossible, such is the complication of the questions involved in their study, to deal with both branches of my subject in a single paper. Consequently I have confined myself, in the present communication, to a description of the positicns and relations of the fragments of Secondary strata, and a discussion of the causes to which these are due. In a third paper, which is already in an advanced stage of preparation, I propose to illustrate the succession of geological events in the Western Highlands during the Mesozoic periods; while in a fourth paper I anticipate being able to conclude the account of my studies of these rocks by an endeavour to deal with those problems of ancient physical geography and general palæontology for the solution of which these rcmarkable fragments of Secondary strata supply such valuable materials.

I. *Introduction.*

For the preservation of the most valuable illustrations of the institutions, manners, and arts of Ancient Rome, the archæologist is indebted to the action of a volcano: the relics of Pompeii have survived in consequence of being buried under the ejections of Vesuvius. To a similar agency, operating at a distant epoch and on a far grander scale, the geologist owes the escape from destruction, in the Western Isles of Scotland, of most wonderful monuments of physical change and highly interesting records of life-history during the Secondary periods; for such, indeed, are those remarkably preserved fragments of sedimentary rocks which it is the object of this memoir to describe.

As he prosecutes an examination and comparison of all the circumstances under which the scattered relics of the Secondary formations present themselves in the West of Scotland, the geologist will be again and again impressed by the extent of the protective influence which the vast masses of Tertiary lava have evidently exerted upon the subjacent stratified rocks. And when he has concluded that survey, he can scarcely have failed to arrive at the conclusion that, but for this protective influence, every vestige of the Mesozoic deposits in the district must have been inevitably swept away by denudation *.

* Those familiar with the geology of Central France will at once recall the manner in which the sheets of basaltic lava capping the great plateaux have, in so many cases, secured the preservation of masses of the lacustrine strata on which they rest, every trace of which must otherwise have been swept away by denuding forces. (*Vide* Scrope's 'Geology and Extinct Volcanos of Central France,' p. 7 &c.)

When, therefore, we reflect upon the remarkable combination of circumstances to which we are indebted for the preservation of these interesting records of the whole series of Secondary formations (from the Trias to the Upper Chalk inclusive) we cannot fail to be impressed by the accidental (and often, indeed, exceptional) nature of the conditions upon which the escape from destruction of fossiliferous deposits has in so many cases depended. It would be difficult to adduce a more striking illustration of the necessarily great imperfection of the geological record than that which is suggested by these strangely preserved fragments, of what were evidently once widely spread formations representing geological periods of vast duration.

It is impossible rightly to understand the features presented by the Secondary rocks in the Western Highlands without carefully studying, in the first place, their relations to the great masses of igneous rocks among which they lie. These relations are of the most intimate and often complicated character. Not only have the fragments of Mesozoic strata which had escaped denudation at the commencement of the Tertiary period, been buried under vast accumulations of lava sheets to the depth of hundreds and even thousands of feet, but they are often, as I shall show hereafter, penetrated by igneous masses connected with three distinct periods of volcanic activity, from the influence of which they exhibit every conceivable stage of metamorphism; and, further, their fragments are found, often in great abundance, imbedded in the vast masses of scoriæ and ashes which have been ejected from the volcanic vents. In order, therefore, to reconstruct the history of the Mesozoic period, it is necessary to carefully restore and reunite all these scattered fragments of evidence; for the same volcanic agency that has so wonderfully preserved the records, has at the same time unfortunately, in too many instances, sadly mutilated and defaced them.

I shall show, moreover, that although during nearly the whole of the Secondary periods the volcanic forces were dormant in the district, yet that era was preceded, as well as followed, by an epoch of the most intense and prolonged igneous activity. The influences of this earlier period of volcanic action in determining the characters of the Secondary deposits, although less marked than those of the succeeding eruptions of the Tertiary period, are nevertheless clearly traceable. Further, many of the peculiarities and anomalies presented by the Secondary rocks in this district appear to find an adequate explanation in the circumstance that they were deposited in the interval between these two periods of violent igneous activity, and that the areas which they occupy may therefore naturally be supposed to have been subject to frequent and excessive disturbance.

But while many points of great importance with respect to the Secondary rocks are thus dependent for their elucidation on a careful study of the volcanic products with which they are so intimately associated, much new light is at the same time thrown upon the nature, age, and history of the latter by an examination of the relations which subsist between them and the interesting fragments of fossiliferous, and thereby *dated*, rocks of the Mesozoic periods.

In this manner we are led to many very interesting conclusions with regard to the chronology of the various rocks of the Scottish Highlands.

Moreover, as I hope to be able to show, the prosecution of this research concerning the relations between these sedimentary and eruptive rocks, is calculated to throw new light upon some of the obscurest problems of physical geology.

Under these circumstances, I have considered it advisable to confine myself in the present communication to this question of the mutual relations between the Secondary and Volcanic rocks of the west coast of Scotland—a question of much complication but at the same time of the highest interest—reserving for a future occasion the details of the history of the Mesozoic periods in the district, as deduced from the palæontological and physical evidence.

1. *History of Previous Opinion on the subject.*—The very intimate manner in which the Secondary and Volcanic rocks of the Hebrides are associated with one another not unnaturally led the earlier geological observers to regard them as being of contemporaneous age. This opinion received its first shock in 1851, through the discovery by the Duke of Argyll of the leaf-beds of Ardtun, and the determination by Professor Edward Forbes of the Miocene age of the fossil plants contained in these deposits*. It then became evident that a part at least of the Volcanic rocks of the Hebrides belongs to the Tertiary period. In 1865 Professor A. Geikie had arrived at the important conclusion that the vast sheets of igneous rock lying between the Secondary strata in the Hebrides are in every case *intrusive*, and therefore not *contemporaneous* with those rocks; and on a review of all the facts of the case, he was led to announce his conviction that the whole of the volcanic rocks under consideration belong to the Tertiary period †. This conclusion I have been able to confirm by showing that the volcanic rocks in question unconformably overlie even the youngest members of the Chalk.

The unmistakably volcanic origin of the so-called "trap rocks" of the Western Isles had been noticed by many observers; and some of these, especially Dr. Macculloch ‡ and Professor Geikie §, have dwelt upon the evidently close relations between these and the Plutonic rocks of the district. The Duke of Argyll has remarked on the manner in which the two classes of igneous rock, as seen in a section in Mull, appear to graduate into one another—and also on the indi-

* Quart. Journ. Geol. Soc. vol. vii. pp. 89, 103.

† Proc. Roy. Soc. Edinb. vol. vi. (1866–67), p. 72, and Quart. Journ. Geol. Soc. (1869), vol. xxvii. p. 283. I gladly take the present opportunity of bearing witness to the great value of Professor Geikie's researches among the volcanic rocks of Scotland. Although the conclusions at which I have arrived are, in many cases, very different from the opinions which he has expressed on some of the phenomena of this interesting district, I think that in almost every case it will be found that the points in which he differs from myself are those in which he has put forward useful suggestions of a tentative character rather than the results of direct observation. In almost every case of the latter kind, I am happy to be able to confirm his great accuracy and acumen.

‡ 'A Description of the Western Isles of Scotland,' 1819.

§ Quart. Journ. Geol. Soc. vol. xxvii. p. 282.

cations of the volcanic character of the mountain of Beinn More, in the same island, afforded by the highly scoriaceous character of its materials*.

Although many very valuable geological observations have been placed on record by Dr. Jameson, Boué, Dr. Macculloch, Principal J. D. Forbes, and Prof. A. Geikie, but little has been hitherto done in the systematic examination of the relations of these old volcanic rocks. The characters of the minerals and rocks themselves, have, however, been much more successfully investigated by several of these authors. Dr. Macculloch's mineralogical knowledge was so large and accurate that the lapse of more than fifty years has failed to deprive his descriptions of the rocks of this district of their interest and value ; and very recently one of the greatest masters of the methods of petrological research, Prof. Zirkel of Leipsic, has supplemented these early observations by a series of careful re-examinations of the same rocks, to the results of which I shall have occasion to refer more particularly hereafter.

2. *Volcanic Origin of the rocks constituting the great plateaux of the Hebrides and the North of Ireland.*—The rocks which constitute such extensive plateaux, both in Ulster and the Hebrides, have long excited attention and interest in consequence of the remarkably picturesque forms which are assumed by them at certain points where the columnar structure is finely developed ; this is especially the case with those justly celebrated localities the Giant's Causeway and the isle of Staffa. That the rocks which present these remarkable characters are of volcanic origin, and indeed constitute the remains of great lava-streams, is a fact which was clearly recognized by some even of the earliest geological observers †; and the more minutely and carefully the phenomena presented by the rocks connected with active or recently extinct volcanoes have been examined, the more strikingly has the soundness of this conclusion been made apparent.

At the present day the volcanic origin of these rocks may be regarded as so far an established portion of geological science as to render quite superfluous on this occasion any details of the grounds on which it rests. Whether we regard the chemical composition of the different varieties of rock, or their mineralogical constitution (especially as this is revealed to us by the microscope), or the peculiarities of their petrographic structure, such as the remarkable vesicular and columnar features which they exhibit,—we are alike struck by the perfect identity of characters between them and the materials of recent lava-streams. Innumerable minor features serve to confirm this conclusion—such as, among others, the highly vesicular or scoriaceous character of the upper and under surfaces of the great masses, the inclusion between them of layers of scoriæ,

* Brit. Assoc. Report (1867), Trans. of Sections, p. 55, and Address to Geol. Soc. 1873, Quart. Journ. Geol. Soc. vol. xxix. p. lxxv.

† *Vide* Sir Joseph Banks, in Pennant's 'Voyage to the Hebrides,' p. 267; A. Mills, in Phil. Trans. for 1790, pp. 73–100; Macculloch, Syst. of Geol. (1831), vol. ii. p. 114, &c.

lapilli and ashes, or the vestiges of ancient soils and vegetation, and the indications exhibited by the surfaces on which these rock masses lie of having been subjected to the action of heat.

One of the most striking points of similarity between these old lavas and those seen to be actually connected with existing volcanoes has, through a very prevalent misinterpretation of the appearances presented, been generally overlooked. I refer to that remarkable peculiarity, connected with the columnar structure, which is nowhere better exhibited than in the beautiful caves of Staffa, and which has been so clearly described by Mr. Scrope as giving rise to such conspicuous features at Pont Gibaud, the Coiron, La Gravenne de Souillols, Jaujac and other points in Central France*. In all these cases the same lava stream is found to be composed of two portions, which at a short distance appear to be very distinctly separated from one another. The lower of these divisions, which usually occupies about one third of the thickness of the lava stream, is composed of very regular, upright, and generally jointed columns, the articulations of which often exhibit remarkable curved surfaces and angular processes. The upper part of the stream, however, presents strikingly different characters, being made up either of nearly amorphous basalt or of thickly clustered columns of small diameter, these being usually curved and twisted in the most remarkable manner. All who have visited Staffa will at once call to mind the contrast presented by the thick upright pillars which form the "Colonnade" and the sides of Fingal's Cave, and the thin, gracefully curved, and intricately interwoven shafts which form the Buchaille, the Clam-shell Cave, and the roof of Fingal's Cave. A careful examination will convince the geologist that the two varieties of columnar basalt form parts of the same lava stream, and are not, as is usually stated in guide-books and geological manuals, the product of two distinct and superposed flows. In the beautiful basaltic columns of the Giant's Causeway, in those of Carsaig, Ulva, and many less known, and more inaccessible localities, I have been able to verify the correctness of this observation.

Mr. Scrope, in an incidental allusion to the phenomena presented by Staffa †, shows that the very striking identity of its features with those so clearly described by him as occurring in Auvergne, had not escaped his observation. He has suggested that the sharp distinction in characters between the two portions of the same lava stream, is due to the different conditions under which they have parted with their heat—that of the upper portion having escaped by radiation, and that of the lower portion by conduction through the subjacent rocks.

3. *Subaerial Origin of these old Volcanic rocks.*—Accepting, then, as amply demonstrated, the conclusion that in these rocks of the North of Ireland and the Hebrides we see the vestiges of extensive lava streams, the next problem which presents itself to the geologist is

* *Vide* 'The Geology and Extinct Volcanos of Central France,' 2nd edit. (1858), pp. 57, 163, 191, &c.

† 'Volcanos,' 2nd ed. (1872) p. 99.

the following:—Were these lavas poured out upon a terrestrial surface? or were they the product of a series of submarine eruptions?

On this question very diverse opinions have been maintained by different authors, the majority, however, being in favour of the submarine origin of the rocks. This opinion has, in a great degree, arisen from the long prevalent idea that the lavas in question were contemporaneous with the Secondary strata with which they are often so intimately associated. We have already pointed out how this opinion has been gradually dissipated—first by the discovery of the Ardtun fossils by the Duke of Argyll, and secondly through the recognition by Professor Geikie of the *intrusive* character, and therefore *subsequent* age, of the sheets of igneous rock which lie in the midst of the Mesozoic strata. With the supposed evidences of the Secondary age of these lavas the grounds on which their submarine origin was maintained have also disappeared; and from the overwhelming and irresistible mass of evidence which I am now able to adduce upon the subject, it will, I think, be accepted as conclusively demonstrated that the lavas were unquestionably of *subaerial* or *terrestrial* origin.

The first point to which it is necessary to allude, is the total absence of marine sediments and fossils, of contemporary age, interstratified with the great lava sheets which we are considering. It is true that this evidence is of a negative character; but when we reflect on the duration of the periods required for the gradual accumulation of these enormous masses of lava, and on the ample proofs which exist of the occurrence of long intervals of time between the outflow of sheets now directly superimposed the one upon the other, we cannot but be impressed by the consideration that, if such an accumulation of lavas took place upon the sea-bottom, beds of stratified materials containing marine organisms must, at some points at least, have been deposited in the intervals between the successive outflows of igneous rock. The actual comparison of the volcanic rocks of the Hebrides and Ulster with others of undoubted submarine character, like those of Central Scotland (which we shall have to refer to more particularly in the sequel, and in which the interbedding of masses of aqueous and igneous origin respectively is such a constant and characteristic feature), lends additional weight to the presumption against the submarine origin of the former.

But this presumption, derived from indirect and negative evidence, must be regarded as a conclusion satisfactorily established by all who will examine and weigh the strong, numerous and cumulative proofs of a direct kind which can be adduced in its support. These it will be necessary briefly to detail.

The highly vesicular and scoriaceous character of many of the Tertiary lavas seems to be inconsistent with the supposition that they have been poured out under a considerable depth of water, the pressure of which would probably prevent that extensive liberation of volatile materials which has so evidently taken place. Some of the lava beds must, in consequence of this operation, have origin-

ally constituted a mass as porous as a sponge, though subsequently converted, by the chemical action of infiltrating water, into solid amygdaloidal rocks *.

In the second place I would direct attention to the nature of the surfaces over which the first emitted lavas have flowed. Thus, in the North of Ireland, where the lavas rest directly upon the chalk, the old surface of the latter was not only one of great irregularity, abounding in hills and valleys, but it is almost everywhere covered with an accumulation of perfectly angular chalk-flints; these superficial deposits, too, often fill "sand-pipes," which penetrate for considerable distances into the mass of the chalk rock. No one familiar with the characteristic modes of weathering of the chalk can fail to recognize in these appearances the evidences of subaerial action. At other points, as indicated by Portlock in the case of Slieve Gallion and Rathlin Island, there are found, interposed between the old chalk soils and the superincumbent lavas, beds of lignite containing wood and amber, which are unquestionably the remains of old forests belonging to the period immediately preceding that of the emission of the lavas. In other cases, again, as in Morvern, we find, in a similar position, thick beds of unstratified ash or volcanic dust†. But in no instance, so far as I am aware, do the surfaces of the rocks immediately underlying the lavas exhibit the slightest indication of having been subjected to the action of marine denudation.

In the third place, when we examine the deposits interposed between the different lava sheets, and which were evidently formed during the intervals between their eruption, we find numerous indications of the prevalence of terrestrial, fluviatile, and lacustrine conditions, but never in any instance of those of a marine character.

(1) Bands of clay or earth, usually only a few inches in thickness, and of a bright red colour, very frequently occur between the sheets of Tertiary basalt both in Scotland and Ireland. These appear to be identical in character with the beds of *soil* formed by the weathering of the surface of one lava stream and destroyed by burning when overwhelmed by a new sheet of lava. This phenomenon, as pointed out by Sir Charles Lyell, is frequently exhibited in existing volcanoes ‡.

* By this infiltration various minerals have been formed in the cavities of the vesicular lava. By very simple chemical reactions the felspars yield zeolitic minerals, while the pyroxenic constituents are converted into various hydrous, magnesian, and ferruginous silicates. More complete decompositions result in the production of chalcedony and calcspar. It is a noteworthy circumstance, capable of frequent verification in the district under consideration, that in rocks containing numerous amygdaloidal cavities the mass of the rock is always much decomposed, and often has passed into a "wackose" condition, through the partial removal of its materials by solution.

† These beds precisely resemble in character those which are found in connexion with volcanoes but recently extinct. Thus, for example, in the island of Lipari we find a fine-grained ash of chocolate-brown colour, full of small decomposed fragments of white colour (probably fragments of crystals of felspar), which is quite undistinguishable from the rock referred to in the text.

‡ "On the Lavas of Etna," &c. Phil. Trans. 1858, pt. ii. p. 711. During a recent examination of many of the most interesting volcanic districts of the

(2) Masses of vegetable matter, at times containing recognizable trunks and branches of trees, in some cases converted by the heat of the overflowing lava into a kind of charcoal, and at others constituting beds of lignite or coal, which are often of fair quality and considerable thickness, but seldom of great extent or very constant character, are by no means of unfrequent occurrence between the sheets of Tertiary lava. Such relics of the vegetation of the periods during which the great sheets of basaltic lava were formed have been found at many points in Ireland—also in the Isle of Mull, near Carsaig, at Loch Lathaich and Loch Scridain—in Morvern, Ardnamurchan and the islands of Eigg and Canna—and in Skye, at Talisker, Scoribreck, Portree, Camiskianevig, Loch Grisornish and other points. Attempts to work these masses of coal and lignite have been made at various times, especially at the Giant's Causeway in Antrim, at Carsaig in Mull, and at Portree in Skye. In the case of the last-mentioned locality 500 or 600 tons of fuel is said to have been obtained; but, as might be anticipated, the deposits have been found to be too irregular in thickness and inconstant in character to repay the cost of extensive operations. Owing to the high price of coal, the well-known lignite bed at the Giant's Causeway was again opened out by the country people during the winter of 1872; and I thus had an opportunity of studying its characters. It is evidently the vestige of an old *forest* overwhelmed by a lava stream. At its base is an "underclay" formed from the decomposition of the older lava bed on which it rests, and intermingled with much vegetable matter; the substance of the lignite itself is made up of great masses of wood, still very clearly exhibiting its tissues; while the upper portions of the mass, which are in contact with the overlying lava, have been converted by heat into a kind of charcoal.

(3) In the interesting section of Ardtun we have evidence of *mud streams* (such as are so commonly formed in the vicinity of volcanoes in action) having overwhelmed and buried the deposits of fine sediment with leaves that had accumulated in pond-like hollows of an old land surface. These mud streams have evidently, during part of their course, flowed over a disintegrated surface of the chalk rocks of the district, and have thus caught up in their mass many unworn chalk flints and angular fragments of the highly indurated Scottish chalk *. The remains of many similar old mud

Mediterranean area (which, through the kindness of Mr. Scrope, I have been enabled to make since this paper was read) I have had the opportunity of seeing how completely in this, as in innumerable other instances, the products of still active volcanoes agree with those which are connected with vents long since extinct, like those on the west of Scotland.

* At the time of the discovery and description of the interesting Ardtun beds the fact of the existence of rocks of chalk and flint *in situ* in the island of Mull was unknown. The angular fragments in the mud-stream of Ardtun, which have been called lapilli, are really portions of the peculiar indurated siliceous chalk of the district, as, indeed, seems to have been strongly suspected by the Duke of Argyll at the time. The manner in which fragments of rock of all sizes, many of them perfectly angular, are mingled together in a fine-grained paste, seems to me to be inexplicable on any other supposition than that

streams, but without the interesting accompaniments of the leaf-beds and entangled chalk detritus which occur at Ardtun, have been found by me in various parts of the Hebrides. An example of a very thick mud-stream buried under lava occurs on the shores of Loch Tuadh in Mull, opposite to the adjoining island of Ulva.

(4) Professor Geikie has called attention to the existence at the Innimore of Carsaig of a bed, mainly composed of chalk flints, which is interposed between the sheets of basaltic lava and attains in some places a thickness of 25 feet. A careful examination of this very interesting deposit convinces me that we have here preserved portions of an old *river-gravel*, formed by a stream which flowed over the surface of the land, in the interval between the outflow of the two lava streams which enclose it. The gravels are composed of flint detritus of every degree of fineness, mingled with rounded fragments of the local hard chalk and of the basaltic lavas of the district; the deposit, which thins out rapidly both eastward and westward, exhibits the alternations of beds of coarse and fine-grained materials, with occasional seams of sand and loam, the whole being marked by much false-bedding; indeed, so far as it is exposed in the sections, this interesting mass of gravels, included between the Tertiary basalts, is perfectly similar in every respect to the familiar gravels of existing rivers. It is evident that the stream which formed these gravels must, in the higher part of its course, have flowed through a valley cut in the chalk strata. I have found in other cases masses of gravel formed wholly of pebbles of the different igneous rocks, which have all the appearance of having been formed by streams cutting valleys in the older lavas and covered up by subsequent outbursts; but these of course exhibit much less striking characters than the deposit of the Innimore of Carsaig.

(5) At very numerous points, both in the North of Ireland and in the Western Isles of Scotland, we find deposits of pisolitic iron-ore interbedded with the basalts. That the materials of these ferruginous masses were derived from the basaltic rocks on which they rest there can be no doubt. The actual agency which effected the concentration of the iron appears to have been that indicated by Mr. David Forbes *, namely the multiplication of organisms of a similar kind to those which have formed the well-known "lake-ores" of Sweden in recent times. This view is confirmed by the occurrence, in association with some of the beds of pisolitic ore, of masses of stratified ash, sand, conglomerate, &c., sometimes containing numerous plant-remains, which are evidently of *lacustrine* origin. Such are the deposits of Ballypalidy in Antrim, at which

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suggested by His Grace, that they were entangled in a mud-stream. The discoloration of the chalk-flints, supposed to be due to the active heat, I regard as being the result rather of weathering operations. At Somma and Bagno Secco in the island of Lipari we find stratified volcanic tuffs with leaves and other plant-remains, which present a very striking resemblance to those of Ardtun, Ballypalidy, &c.

* Quart. Journ. Geol. Soc. vol. xxvi. (1870), pp. 164, 165.

place the extensive workings that have now taken place have exhibited sections which leave no room for doubt as to the true character of the beds. I have found sections of precisely similar deposits on the shores of the Sound of Ulva, and at other localities in the Hebrides. The frequency with which lakes, shallow lagoons, and pond-like hollows are formed in a district subject to volcanic eruptions—in consequence of local subsidences, through the damming up of river-courses by lava-streams, or through the formation of "pit-craters" by explosion, has been dwelt upon both by Mr. Scrope and Mr. Darwin.

(6) Local masses of unstratified volcanic dust, ashes, scoriæ and conglomerate are, by no means rarely, found intercalated with the great streams of lava.

The whole of these facts point to the conclusion that, during the period of the emission of the great lava floods which form the enormous plateaux of the Hebrides and Antrim, the surfaces over which they flowed were above the sea-level, and, further, that intervals of sufficient duration occurred between the outpourings of the lava streams to admit of the formation of those very interesting intercalated deposits, which are in every case of a terrestrial, fluviatile, or lacustrine origin.

4. *Evidences of the Former Existence of great Volcanic mountains in the district.*—In the foregoing paragraphs we have shown that we are led to the inevitable conclusion, not only that the great plateaux of the Hebrides and the north of Ireland were formed by the gradual accumulation of a long succession of lava-flows, but that, like the similar lavas of Sicily, Auvergne, and Iceland, they were actually poured out on the surface of the land.

Now, in all the cases of recently formed lavas (to which we have had such frequent occasion to refer as exhibiting so perfect an identity in character with the ancient rocks which we are describing), their extrusion has been accompanied by the piling up of ejected fragmentary and semifluid materials around the vents, so as to form those more or less conical mountain-piles which we call "volcanoes;" and it is from the summits or sides of these that the great lava streams have usually flowed.

Can we then hesitate to accept the conclusion that rocks which present such a remarkable identity in characters, even to the minutest details, must have had a similar origin?—that the formation of these ancient subaerial lavas was attended with the production of phenomena similar to those which, at so many different points of the earth's surface, we still observe to be the constant effects of volcanic action?—that, in short, within our British district there once existed volcanoes from which those great volumes of igneous materials we have been describing were ejected?

Further, when we reflect upon the fact (one patent to the most casual observer of the geology of the district) that the masses of these ancient lavas which remain for our study, notwithstanding their vastness, are nevertheless mere isolated relics, which have escaped destruction by denudation, of plateaux which must originally have

covered many thousands of square miles*—that, moreover, these fragments which remain still constitute mountains nearly 2000 feet in height, entirely made up of almost horizontal lava sheets,—must we not conclude that the volcanoes from which these wide-spreading and thickly piled masses of lava were ejected could have been of no mean dimensions or insignificant character?

At what points, then, were these great volcanoes situated? Where are the relics of their vast masses, the indications of their violent action? Can it be that all traces of such great mountain-piles, belonging as they do to one of the most recent of the geological periods, have altogether disappeared? Or are we rather to conclude that denudation and other causes have so modified and disguised their characters, that their true nature is not now at first sight recognizable? These are the questions that everywhere present themselves to the geologist in the Western Highlands, and press for a solution.

In support of the opinion that, even within a comparatively recent geological period, such vast volcanoes may have entirely disappeared, while extensive fragments of the lava streams which flowed from them so conspicuously remain, it may be pointed out, first, that the former would be composed mainly of loose and fragmentary materials, which are much more easily acted upon by degrading forces than the solid rocks of the latter; secondly, that their greater elevation would facilitate their destruction; and, thirdly, that the evidence of denudation, even on the most stupendous scale, having taken place in the district since the period of the formation of these volcanoes, geologically recent though they are, is of the most unmistakable character.

But on the other hand it must be remembered that the remains of the great volumes of fluid materials which ascended through the volcanic piles, and, sending off ramifications in all directions, served to bind together the masses of fragmentary matter, must not only in themselves have constituted rocks of great solidity and permanence, but, by affording coherence to the volcanoes have retarded their denudation. Of these solidified igneous springs, which constituted the connexions between the great rivers of lava and the subterranean reservoirs of liquefied rock, it is hard, nay, impossible, to conceive the remains to have been wholly removed while any portion of the older rocks which they penetrated remained; though in many cases we can readily understand the effects of denudation to be such as to render obscure the connexion between these solidi-

* It is perhaps not possible to adduce any more striking illustration of the vast changes which have taken place in the relative position of rock-masses, and the extent to which they have been subjected to denuding agencies since a period so geologically recent as the Miocene, than that which is afforded to us in the great fault at Morvern. Here we find a mass of strata composed of Lias unconformably overlain by Upper Cretaceous, and this in turn by Miocene basalts, let down by a fault, which must have a throw of nearly 2000 feet, against the contorted gneissic rocks of the Lower Silurian. Nothing can present a greater contrast than the green terraced hills of the former, rising in Glashven to the height of 1516 feet, and the barren and rugged mountains of the latter culminating in Garbh-shlios (1638 feet). The abrupt junction of these rocks can be traced in the wild ravine of Innimore.

fied reservoirs and rivers, through the removal of all traces of the ducts which once connected them with one another, and which must have necessarily existed at higher elevations than either of them.

In the following pages I hope to be able to supply a complete and satisfactory solution of the interesting question of the *position* of the vents from which the great lava streams so conspicuous in the north-western part of the British archipelago originally flowed; and even of the *dimensions* and *features* of these old volcanoes I hope to be able to furnish some data for forming a judgment. At the same time I shall exhibit, in its outlines at least, the history of the long series of volcanic eruptions to which the rocks of this district owe their accumulation. Further, I believe that it will be possible, from these interesting examples, to deduce some important conclusions as to the modes of operation of volcanic action, especially of that by no means insignificant part of it which takes place far below the surface, and which, in the nature of things, can never be observed by us in volcanoes which are still active or but recently extinct; for in these the mountainous piles of ejected materials altogether conceal the underlying rocks. Even in the cases of the deepest ravines on the flanks of existing volcanoes (and I do not here except even the wonderful natural sections of Somma and the Val del Bove), interesting as these undoubtedly are, the insight afforded to us of the internal structure of the mountains must be at the best very partial indeed; but in the Hebrides I shall show that we have supplied to us that great geological desideratum—a number of volcanoes so dissected by the scalpel of denudation as to constitute, as it were, a series of anatomical preparations, from which we may learn directly the internal structure of the piles, and obtain bases for reasoning on the causes to which that structure owes its origin. Thus the study of these ancient volcanoes is, as I believe, calculated to throw new light upon some of the most difficult problems of physical geology.

As I have already intimated, we have, in the west of Scotland, the relics of two great and widely separated periods of volcanic action: one of these was evidently of earlier date than the deposition of the Mesozoic strata which unconformably overlie its products; the other was certainly of later date than the formation of the Secondary rocks, upon which its products are everywhere superposed, and through which they are intruded. As might be anticipated, the relations between the various products of the two volcanic series and the intermediate Secondary strata are often of the most intricate character.

For the purposes of the present argument it will be convenient to discuss, in the first instance, the characters presented by the younger series of volcanic rocks, as these, owing to their comparatively better state of preservation, often throw much light on the internal structure and the true relations of volcanic masses. Guided by the analogies of this younger series of rocks, we shall be the better prepared to decipher the more obscure, because less perfectly preserved, relics of the older series of similar products.

II. *The Tertiary Volcanoes.*

1. *Classification of the Tertiary Volcanic Rocks.*—In approaching the consideration of this part of my subject, I hasten to acknowledge the important assistance which I have received from the very valuable memoir of Prof. Zirkel, of Leipzig, entitled "Geologische Skizzen von der Westküste Schottlands"*, which made its appearance in 1871. This author, who is so well known for his important contributions to petrology, made a tour in the Hebrides in 1868, and in the memoir referred to has given an admirable sketch of all that had hitherto been done in the elucidation of the geological structure of the district, accompanied by the details of his microscopic studies of the various specimens of rocks collected by him.

Bearing in mind the backward state of petrological investigations in this country, I have in the present memoir almost uniformly followed the classification and adopted the nomenclature of Prof. Zirkel. The few instances in which I have departed from his terminology, such as, for example, in avoiding the use of the terms "porphyry" and "amygdaloid," and employing their adjective derivatives instead, will, I hope, commend themselves to all geologists. In the case of rocks not noticed by Prof. Zirkel in the memoir cited, I have endeavoured as far as possible to make my use of terms correspond with the definitions given by the same author in his very admirable 'Lehrbuch der Petrographie,' published in 1866.

In studying these rocks and minerals I have also to acknowledge the valuable assistance of Mr. David Forbes, F.R.S.; of Mr. Thomas Davies, of the British Museum; and of Mr. Rudler, of Jermyn Street.

The Tertiary volcanic rocks constitute two well-marked parallel series. Each of these series has at one end of it a highly crystalline rock, and at the other a perfect glass; while the intermediate terms constitute the most complete and insensible gradation between these two extremes. The *ultimate* chemical composition of the rocks of either series is identical in all the members of it, or rather varies between the same comparatively narrow limits. But the average composition of the rocks of the two series presents the most marked contrast when compared with one another.

These two series of igneous rocks have long been recognized by petrologists as occurring both in recent volcanoes and in association with the strata of every geological period. From the marked difference in the quantity of silica which they contain they have been designated the acid and basic series: the former is sometimes known as the felspathic, orthoclastic, or trachytic series; and the latter as the augitic, plagioclastic, or basaltic.

In the members of the acid series of igneous rocks the percentage of silica varies from 60 to 80, averaging about 70; while in the basic its limits are 45 and 55, and its average 50. In the former class of rocks the proportion of alkalies is comparatively large, and that of the alkaline earths and the oxides of iron and manganese small; but in the latter, lime, magnesia, and oxide of iron con-

* 'Zeitschr. d. deutschen geologischen Gesellschaft,' Jahrg. 1871, pp. 1–124.

stitute a very large proportion of the mass, while the quantity of soda and potash is comparatively insignificant.

The contrast between the ultimate composition of the rocks of the two series is illustrated in the following Table :—

	Acid series.			Basic series.		
	Max.	Average.	Min.	Max.	Average.	Min.
Silica	80	72	61	55	50	45
Alumina	19	15	10	18	14·5	10
Alkalies	20	7	0	8	3·5	0·5
Alkaline earths	8	2	0	29	17	8
Oxides of iron and manganese	5	2·5	0	19	14	8

In the acid series the highly crystalline form is known as granite, the glass as pitchstone or obsidian. The intermediate terms of the series have received a great number of names, only a few of which it will be necessary to notice here.

In the basic series the most highly crystalline form is known as gabbro, the glass as tachylite ; and the intermediate forms are also, as in the former case, very numerous.

In the accompanying Table (p. 235) the composition of the principal rocks of these two series is illustrated ; the averages are for the most part those calculated by Durocher ; in the instances marked by an asterisk I have been compelled to employ averages calculated by myself from published analyses.

The Tertiary granites consist essentially of two species of felspar with quartz, and either mica or hornblende, or both of these minerals together. These granites often, but by no means uniformly, present a somewhat cavernous structure, in which case the constituent minerals are found with perfectly terminated crystals projecting into the cavities of the rock. The felspars consist of orthoclase and oligoclase, with much more rarely albite also ; their crystals often present a pale brown or buff colour, owing to the partial decomposition of ferruginous materials entangled in them. When, however, the rock is quarried at some depth from the surface the felspars are usually seen to be of a beautifully white colour ; while more rarely they present pink and reddish tints. The quartz is usually white, but not unfrequently smoky, and in rare cases black ; it sometimes forms perfect crystals. The felspar and quartz make up the mass of the rock, which is always a highly silicated one ; and the magnesian and ferruginous silicates are present only in comparatively small quantities. In the deeper and more central parts of the great granitic masses the rock is micaceous ; but as we pass

Table Illustrating the Average Ultimate Chemical Composition of the Rocks of the Acid and Basic Series.

Acid Series.

	Specific gravity.			Silica.			Alumina.			Potash.			Soda.			Lime.			Magnesia.			Oxides of iron and manganese.		
	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.
Granite	2·73	2·66	2·60	78	72·8	66	18	15·3	11	9	6·4	4	2·5	1·4	0	1·5	0·7	0	2	0·9	0	2·5	1·7	0·5
Syenite-granite ...	2·75	2·68	2·63	72	69·0	64	17	15·0	12	6	4·2	3	3·5	2·8	1	4	2·2	1	4	2·6	2	5	3·2	2
Felsite *	2·70	2·65	2·60	81	74·3	68	15	13·1	11	8	4·4	2	5	2·8	0·5	3	1·2	0·5	1·5	0·6	0	5	2·8	1
Felstone	2·63	2·64	2·58	80	75·4	68	18	15·0	11	6	3·1	2	6	1·3	0	2	0·8	0	2·5	1·1	0	4·5	2·3	0·5
Pitchstone &c. ...	2·36	2·34	2·31	74	70·6	62	17	15·0	11	6	1·6	0	3	2·4	1·5	1·5	1·2	1	2	0·6	0	4	2·6	1

Basic Series.

Gabbro	3·10	2·95	2·85	54	49·0	45	17	15·0	12	1	0·3	0	4	2·5	0·5	14	9·5	6	15	9·7	7	14	11·5	8
Augitic-gabbro * .	3·90	2·90	2·75	54	49·8	45	20	16·5	14	3	1·7	0·8	6	3·9	2	11	7·9	4·5	7	5·4	4	16	13·0	8
Dolerite	3·10	2·95	2·85	55	51·0	45	16	14·0	12	1	0·2	0	5	3·4	2	13	10·0	7	9	5·5	3	18	14·7	9
Basalt...............	3·10	2·96	2·85	53	48	42	18	13·8	10	3	1·5	0·5	5	3·0	2	14	10·2	7	10	6·5	3	16	13·8	9
Tachylite *.........	2·54	2·52	2·50	56	54·3	50	18	16·0	12	4	1·8	0·5	5	4·0	3	8	7·2	6	6	2·8	0·5	13	11·2	10

towards the higher and outer parts the mica is gradually replaced by hornblende, and the rock passes through the varieties of hornblendic granite into syenite-granite. The adventitious minerals in these granites are pyrites, marcasite, chalcopyrite, garnet, apatite, and epidote. The texture of the rock varies greatly, from coarse and sometimes porphyritic varieties to others so finely granular that they might be mistaken at first sight for sandstone.

By the disappearance of the crystals of hornblende (which appear to be replaced in many instances by some easily decomposable mineral, lining the cavities of the rock) the syenite-granites pass into felsites. These exhibit every variety, from the most granitic forms, like eurite, to others which have been called *quartz-trachyte*, from which volcanic rock, indeed, they are in no way distinguishable. These felsites are usually quartziferous, and sometimes very highly so; at other times they are almost wholly made up of crystals of felspar, imbedded in an amorphous paste; and not unfrequently they exhibit the porphyritic structure.

When the felspathic rock becomes compact, as it usually does in the lava streams, it may be called felstone. The felstones of the Hebrides vary in colour from black, through various shades of green and grey, to white; but in almost all cases their surfaces acquire a white crust as the consequence of weathering action. By this circumstance, and also by the manner in which they withstand denuding influences, preserving everywhere the striæ and *roche-moutonnée* forms impressed upon them during the glacial epoch, the felstone-lava streams are strikingly distinguished from the basaltic. Both, however, exhibit the columnar structure (though with characteristic peculiarities in either case), the globular forms developed by weathering, and the amygdaloidal structure, which in both is developed to the greatest extent at the upper and under surfaces of each lava stream. The felstones appear to be highly siliceous trachytic lavas which have undergone more or less alteration; and occasionally, by weathering action, the obliterated banded and sphærulitic structures so commonly found in, and so characteristic of, quartz-trachytes*, are restored in their ancient representatives, the felstones.

When the same rock becomes glassy in structure it is pitchstone or obsidian, the former name being properly applied to the varieties with a resinous, and the latter to those with a vitreous lustre.

In the various intrusive masses and veins the several forms of highly felspathic rock are found passing into one another by the most insensible gradations.

In the basic series of rocks the place of granite is occupied by *gabbro*, a rock which, from the similarity of its mode of occurrence and behaviour to that of the former, has been called "granitone" and "granito-di-gabbro." It consists essentially of a plagioclase felspar, one or more pyroxenic minerals, and olivine—the latter mineral being so uniformly present that, according to Zirkel, it must be regarded as an essential ingredient of the rock. The felspar of this rock appears

* See Mr. Scrope "On the Geology of the Ponza Islands," Trans. Geol. Soc. 2nd ser. vol. ii. p. 195.

to be in almost every case labradorite, of white, green, or purplish tints, and often belonging to the beautifully glassy varieties. The pyroxenic ingredient is usually diallage; but this is often replaced on the one hand by hypersthene, and on the other hand by augite, in the same manner as Streng has shown to be the case with the gabbros of the Hartz. In many cases the augite wholly replaces the diallage; and this is found to be always the case as we pass to the higher and outer portions of the great intrusive masses; while occasionally, instead of augite, we find some other variety of pyroxene, such as the beautiful green coccolite. These brilliant varieties of pyroxene, with the glassy labradorite and the peculiar forms of olivine, constitute rocks of great beauty. The olivine is usually filled with innumerable microliths of chromic or titaniferous iron, by which its ordinary aspect is entirely masked; sometimes, however, it presents its usual clear pale-green tint, and at others, through partial decomposition, has assumed a reddish-brown colour. The gabbros vary in structure from aggregates of crystals, sometimes 2 inches in length, down to finely granular rocks. Among the adventitious minerals which they contain, the first place must be assigned to magnetic iron, which is often present in large quantities; pyrites, marcasite, chalcopyrite, biotite, garnet, apatite, and epidote also occur in it; while serpentine and chlorite are among the results of the incipient alteration which is often found taking place in its mass.

When the gabbro in which the diallage is wholly replaced by augite assumes a granular structure, it becomes dolerite; and when still finer grained, it passes into anamesite and basalt; finally, when the basic rock becomes glassy in structure, it is known as tachylite.

Each member of the basic series of rocks can be seen passing into the others by the most insensible gradations. Thus the side of a gabbro vein is often formed by a layer of basalt; that of a basalt vein by one of tachylite.

The parallelism between the different varieties of the acid and basic series of igneous rocks, and the similarity in their modes of occurrence, is very striking. There is one important distinction between them, however, which it is necessary to bear in mind: the crystalline acid rocks (granites) are usually among the most stable and indestructible of the materials of the globe; the crystalline basic rocks (gabbros) are, on the other hand, particularly liable to decomposition, the diallage and olivine giving rise to the formation of various serpentinous minerals.

I have not attempted to describe the interesting details of minute structure which the microscope has revealed in most of the rocks of these two series, but must refer the reader for information on this subject to the excellent memoir of Prof. Zirkel before quoted.

Besides the acid and basic rocks of Tertiary age in the Hebrides, there occur also a few examples of the intermediate forms—such as diorites and syenites among the intrusive masses, and "porphyrites" and phonolites among the lavas. But these are so small in quantity, and so local and exceptional in their mode of occurrence, as not to demand more than a passing notice in this place.

2. *Nature and Origin of the Great Volcanic Rock Masses.*—Confounded under the common name of "trap," several very important distinctions have been, in the case of these igneous rocks, to a great extent lost sight of; these it will therefore be necessary to refer to particularly.

a. *Lavas.*—These, as already noticed, constitute the great mass of the plateaux, which have been cut up by denudation into those terraced hills so characteristic of the district. They are usually composed of compact or crypto-crystalline varieties of rocks, more rarely of the glassy forms (in the case of the acid and intermediate varieties), but never of the largely crystalline or granitic forms. In very many cases they are distinguished by their amygdaloidal character; but the absence of this feature must not be regarded as an evidence that any particular rock is not to be considered a lava; and, indeed, in thick lava streams the amygdaloidal (or altered vesicular) varieties are almost wholly confined to the upper and lower portions of the mass*. The amygdaloidal lavas often exhibit evidence of their vesicles having been drawn out by the flowing of the mass, but in very various degrees in different cases. Both the basic and the acid lavas at times assume columnar characters; but in those of the former class these are much more frequently displayed, and in a more striking form. The basaltic lavas often exhibit the thick regular columns with equidistant joints, cup-and-socket articulations, and angular processes so well known as occurring at Staffa and the Giant's Causeway; in the felspathic lavas, on the other hand, the columns, when present, are usually of smaller diameter and less regular form, while they are often of great length, and never exhibit joints at regular intervals. The masses of felstone lava are seldom found extending to greater distances than ten miles from their centres of eruption; the basaltic lavas, however, have spread in vast sheets to distances of fifty or sixty miles from those centres.

b. *Intrusive Masses.*—These vary in dimension, from the thinnest veins or strings, to vast bosses constituting great mountain-groups like the Cuchullin Hills of Skye, or the deer-forest of Rum and Ardnamurchan. In their ultimate chemical composition they coincide perfectly with the rocks composing the lavas; but in the varieties of their texture and mineralogical constitution they exhibit a much wider range. Thus, while we find veins of basalt in which the rock-structure is identical with that of many of the lavas, we find also others in which the same rock passes into a glass, tachylite; while others, again, are composed of the highly crystalline or granitic gabbro rocks. Similarly, felstone veins are related to those of pitchstone and obsidian on the one hand, and to masses of felsite, syenite-granite, and granite on the other. As a general rule it may be stated that the largest intrusive masses are composed of the most highly crystalline or granitic rocks. Thus the gabbros on the one hand, and the granites on the other, constitute, for the most part,

* The manner in which this character is displayed by almost every recent lava stream is familiar to all who have visited volcanic districts, and has been alluded to by many authors.

great mountain masses; the dolerites and the felsites occur as intrusive sheets or bosses; while the basalts and felstones form narrow dykes and veins, of which the sides and the smaller offshoots pass into tachylite and pitchstone respectively. Sometimes different varieties of rock-texture are exhibited in the same mass; thus the sides of a mass of granite often pass into felsite, and a vein of gabbro is bounded by surfaces of dolerite or basalt. That these masses were actually forced through older rocks, is shown by the manner in which the latter, whether of aqueous or igneous origin, are disturbed in the neighbourhood of the larger masses of the kind; that they were, at the time of their eruption, in a fluid condition, is proved by the manner in which they have occupied even the minutest fissures of the disturbed rocks; and that this fluidity was connected with a great development of heat, is indicated by the changes to which they have given rise in the rocks with which they have come into contact.

The intrusive rocks seldom exhibit the vesicular (resulting in the amygdaloidal) structure; but they are, on the other hand, often columnar. In the case of the larger masses the columns are generally of large proportions, but indistinct character, while in the dykes and veins they are usually small and often very minute, being in all cases arranged at right angles to the surfaces of the intersected rock.

c. *Volcanic Agglomerates.*—But besides the two series of rocks which we have described as constituting by far the greater portion of the volcanic products of the Hebrides, namely the lavas and eruptive masses, there are others of a very remarkable character, which have hitherto almost wholly escaped observation. Like the two classes of rocks just described, these rocks have also been confounded under the general name of "trap." They are always found associated with the great masses of eruptive rock, and are often remarkable for the fantastic forms to which, in consequence of their peculiar modes of yielding to denudation, they give rise. On their fresh surfaces of fracture the rocks of this class often present no peculiarity which would enable us to infer their mode of origin; it is only on the surfaces of masses which have had their remarkable structure "developed" by weathering operations, that these striking features are revealed to us. In the same manner that a highly crystalline and apparently altogether unfossiliferous limestone (like that of Durness, for example) often exhibits on its weathered faces proofs that it was originally made up of a congeries of beautiful organisms, so these apparently structureless igneous rocks are by the same agency made to reassume to a certain extent their original form. The weathered surfaces of the blocks show that the rocks in question are really agglomerates, composed of angular and subangular masses of rock of all sizes, from blocks several tons in weight down to lapilli, volcanic sand and dust. Many of these fragments are shown by the same weathering process to be highly vesicular and scoriaceous, and among them not a few present the peculiar characteristics of entire or fragmentary "volcanic bombs." In many cases crystals of various volcanic minerals, either fractured

or with worn angles or faces, such as commonly occur among the materials ejected from volcanic vents, are found imbedded in these agglomerates.

That these peculiar rocks are really portions of old volcanic piles, and that they are made up of the fragments actually ejected from volcanic vents, no one who has had an opportunity of studying the appearances presented by their weathered surfaces can for one moment doubt. But in the same manner that loose masses of shells and corals have been converted, through the chemical reactions set up by the infiltration of water, into crystalline and apparently structureless limestone, so these old heaps of volcanic cinders have been transformed by similar agencies into rock-masses of great solidity and hardness.

But lest any doubt should still remain as to the real origin of these remarkable rocks, I am fortunately able to adduce a kind of evidence of the same convincing character as that of fossils in the sedimentary rocks. He who would hesitate to accept as evidence of aqueous origin in a rock such physical characters as stratification, oblique lamination, and ripple-marks, could scarcely continue to doubt, if shown in its mass, groups of oysters, bored by sponges and annelids, and overgrown by serpulæ and polyzoa.

In the case of the volcanic rocks, though we cannot adduce the evidence of fossil animals and plants, we can nevertheless point to the characteristic species and varieties of minerals which they contain. Every one is aware that the vents and cones of volcanoes constitute natural chemical laboratories in which many beautifully crystallized minerals are formed which are seldom or never found except in the actual vicinity of eruptive centres. Hence such species and varieties are usually classed by mineralogists as "volcanic minerals." These minerals, as is so well known, are constantly found filling the fissures and vesicular cavities which occur in the various blocks ejected from the volcanic vent; and as has been remarked by Daubeny, Sorby, and other authors, they usually belong to different species and varieties from those which characterize the lava streams which have solidified at some distance from the volcanic vent. The agents concerned in the production of these volcanic minerals appear to be intense heat, combined with the infiltration of water under immense pressure, and the penetration of various acid gases and volatile materials.

Many of the peculiar volcanic minerals are of remarkably unstable character; and of these it would be as unreasonable to expect the preservation as that jelly-fish, lobworms, and the soft tissues of animals and plants should be found in sedimentary rocks. But the more stable species of volcanic minerals actually do occur in a "fossil state" in the midst of the volcanic agglomerates of the Hebrides; and the preservation, under favourable conditions, of their often delicate and beautiful crystals is the result of a remarkable series of operations. In the first place, by infiltration, the masses of crystals are surrounded by, and imbedded in, a mass of zeolitic minerals which is formed by the decomposition of the felspars of the lava; and thus carefully packed they escape further injury. Subsequently, on the exposure by denudation of the rock-masses, the "cotton-wool" of zeolitic materials is

gradually removed: and, under favourable circumstances, the original crystals are sometimes thus again exposed, exhibiting all their pristine lustre and beauty. Among the minerals thus occurring many beautiful varieties of the epidote and garnet groups are especially conspicuous. Some of these minerals appear to have been formed in the fissures of masses of rock which were ejected from the volcanic vents; others may have originated from the action of various gases upon the materials of the lava during the "solfatara stage" of the volcano's history.

d. *Volcanic Breccias.*—The rocks of the last-mentioned class pass by insensible gradations into those which it is now our purpose to describe. Scattered through the masses of the agglomerates of scoriæ and ashes, we find blocks of stone of the most various kinds, which are evidently of foreign origin; and in some cases these become so numerous that the rock may be described as a breccia composed of fragments of foreign rocks imbedded in a matrix of volcanic ashes, sand, and lapilli.

That these angular blocks, which vary in size from masses several tons in weight down to the smallest fragments visible to the naked eye, were actually ejected from volcanic vents, we should be justified in concluding, not only from the analogy of existing volcanoes, but from the confused and irregular manner in which they lie in the masses of evidently erupted volcanic materials *. Fortunately, however, we can point to facts which are altogether conclusive as to the origin of these blocks. They are found to belong, in every case, to the particular rocks through which the volcanic vent which they surround has been opened. Thus in the island of Rum (where these volcanic breccias are admirably displayed, as we shall see hereafter), which forms the central part of an old volcano that has burst through rocks of Cambrian sandstone, the blocks in question consist exclusively of materials derived from that formation; in Mull a great volcano has originated in the midst of various Palæozoic and

* The frequency with which blocks torn from the rocks underlying a volcano are thrown from its vents during eruptions is a fact familiar to all students of volcanic geology. Alike in the old agglomerates of Somma and among the modern ejections of Vesuvius, there abound fragments of those stratified rocks in the midst of which the great fissures to which the Neapolitan volcanoes owe their origin have been opened. The so-called "lava" ornaments of Naples are made from the limestones, often more or less dolomitized, of these ejected blocks; while from the cracks and cavities of the same are derived the greater portion of those beautifully crystallized specimens which have made Somma and Vesuvius so preeminently famous among mineralogists. The blocks thrown out of the great Neapolitan volcano were, for the most part, evidently derived from the Subapennine (Tertiary) strata; but some from the Apennine (Secondary) rocks also occur. My friend Prof. Guiscardi, of the University of Naples, was, in 1856, able to give a list of no less than 112 species of fossils derived from the blocks thus ejected from the crater of Vesuvius (see his "Fossile Fauna des Vesuvs" in Roth's 'Der Vesuv und die Umgebung von Neapel,' 1857); and this list he has since increased. Near the great crater now occupied by the Lago Bracciano, I found great masses of volcanic agglomerate containing such enormous quantities of angular fragments of Subapennine limestone as to constitute "volcanic breccias" greatly resembling those of Mull which are referred to in the text.

Secondary strata, fragments of the whole of which occur in the volcanic breccias; while at Beinn Shiant, a volcanic vent having been opened in a tract made up of older lavas, easily recognizable portions of these occur in the great masses of agglomerate which constitute a portion of the relics of the volcanic cone.

In many cases such ejected blocks exhibit evidence of having been submitted to a certain amount of heat. Being often composed of materials of much more indestructible character than the consolidated ashes &c. in which they are imbedded, they are frequently left lying, like the included blocks of masses of Boulder-clay which have been destroyed by denudation, upon the surfaces of the mountains; and for these, indeed, they may, by a casual observer, be easily mistaken in some instances. Such an idea, however, is at once removed by an attentive study of the whole of the phenomena and conditions of the case.

3. *Relations of the Volcanic Rocks to one another and to the Older Deposits in the Island of Mull.*—We now turn to the consideration of the very interesting question of the manner in which the several kinds of volcanic products, which we have described in the preceding pages, are associated with one another, and of the positions which they occupy with respect to the strata of the Palæozoic and Mesozoic epochs. Owing to a peculiar combination of favourable circumstances, which will be more particularly described in the sequel, the island of Mull furnishes us with a most complete and beautiful illustration of the relations which the volcanic rocks bear to one another; and we therefore propose, in the first instance, to describe the structure of this district.

The island of Mull, with the adjacent peninsula of Morvern and various small surrounding islands, form portions of a great plateau, composed of sheets of basaltic lava piled upon one another to the depth of nearly 2000 feet. This plateau, which is now broken up by denuding agencies and traversed by numerous fiords and sounds, is, on its southern side, brought into abrupt contact with the Palæozoic rocks through the agency of a great fault, which has a throw of at least 1600 feet.

In the centre of this basaltic plateau rises a group of lofty mountains, about twelve miles in diameter, many of the peaks of which rise to heights of from 2000 to 3000 feet above the sea-level, while one of them, Beinn More, attains an altitude of no less than 3172 feet.

Nothing can be more striking than the contrast presented by the mountain-peaks of this central group of mountains and the eminences of the surrounding plateau. While the latter are everywhere characterized by those remarkable tabular and terraced forms which have suggested the name of "trap" (forms which, by constant repetition in these districts, tend to become monotonous), the former exhibit the most wonderful diversity of outlines—lofty, smooth, pyramidal masses, like Beinn Tsalla, being mingled with wildly irregular, and fantastically shaped peaks, like Beinn Buy, Creach Beinn, Beinn Varnach, Dun-da-gu, and Craig Craggen.

A very slight examination of the rocks of Mull is sufficient to

explain the cause of the differences presented by the mountains of the central and outer portions of the island respectively. While the latter are made up of nearly horizontally disposed lava streams, the former consist of a number of intrusive masses composed of rocks of very various degrees of hardness, and associated with great deposits of volcanic agglomerates and breccias—the several rocks yielding, as might be anticipated, to denuding forces in very unequal degrees and in very various manners.

The positions and relations of the rocks of Mull are illustrated in the accompanying plan and sections (Pls. XXII. & XXIII.). In these an attempt has been made to exhibit the relations of the different rock-masses by employing different colours for the two great varieties of igneous rocks, while the variations in the depth of tint in either case serve to indicate their crystalline, stony, or glassy character.

Forming the basis of the great central mountain-group of Mull are masses of highly siliceous intrusive rocks. Where great valleys have deeply intersected these masses, they are seen to be composed of granite, usually of the hornblendic variety, but passing, in the deepest and most central portions of the masses, into ordinary granite with mica. But in proportion as we trace the rocks of the mass outwards and upwards, we find the granite passing by insensible gradations into felsite. Lying upon the skirts of these central bosses of granitic and felsitic rock are thick masses of felstones, disposed in regular sheets and of amygdaloidal structure, which alternate with beds of scoriæ, lapilli, and ashes, containing many included blocks of the stratified rocks of the island. While these latter undoubtedly represent the lavas and fragmentary materials ejected from a volcanic vent, the central hills of granite and felsite are no less certainly great eruptive masses; and that this is the case is proved by the fact that they give off numerous veins both into the overlying felstone lavas &c. and into the surrounding older strata, which veins are often seen to have entangled fragments of the various rocks which they traverse.

Rising through the midst of these masses of granitic and felsitic rocks, and constituting the bulk of Beinn Buy with parts of the surrounding mountains of Creach Beinn, Beinn Varnach, and Beinn Tsalla, we find a great mass of gabbro or basic rocks from which there proceed in every direction innumerable veins, sheets, and intrusive masses of irregular form, that traverse the whole of the highly siliceous rocks in every direction. In these great intrusive masses of gabbro the pyroxenic ingredient in the deeper and more central parts appears to be diallage and hypersthene, which minerals are replaced in the peripheral portions by various forms of augite. As we trace the gabbros into the numerous veins which proceed from the central mass, they are found to graduate into dolerites, exhibiting every degree of coarseness of grain, and through these into ordinary basalt. In the latter condition the veins and dykes often proceed to great distances from the central mass, intersecting alike the lavas of the great plateaux and the various Primary and Secondary strata which underlie them (see Pl. XXIII. fig. 1).

Owing to the very different modes of weathering of the igneous rocks of the acid and basic series respectively, it is comparatively easy for the geologist to study the relations which they bear to one another. This study is conclusive as to their relative age and position. The rocks of the acid series were first extruded and consolidated; and subsequently there was forced through their midst a fluid mass of basic materials penetrating the innumerable fissures of every size which, by the upheaving force, were rent alike in the earlier-formed igneous rocks and the surrounding strata.

Overlapping the edges of the felstone-lava series we find the basaltic lavas of the great surrounding plateaux; and that these once entirely buried the former is shown by the small outlying portions of basalt which at some points still remain capping the felstones.

Finally, we must notice that all round the central masses of eruptive rocks there occur patches of volcanic agglomerate and breccias, alternating with lava-sheets and traversed by innumerable veins and dykes. These patches constitute the last remaining vestiges of the great conical piles of fragmentary materials which so frequently surmount volcanic vents. As will be hereafter shown, they belong to two different periods of eruption.

Of the rocks upon which the streams of lava which constitute so large a portion of Mull were poured out, and through which the great eruptive masses of the central portion of the island have forced a passage for themselves, we are not left in doubt. At the south-western extremity of the island the peninsula of the Ross of Mull, consisting of Lower Silurian gneiss and mica-schist, with an eruptive mass of granite (which will be shown hereafter to be of later Palæozoic age), stretches beyond the lavas of the great plateau, and is continued in the proximate island of Iona, composed of rocks supposed to be of Laurentian age. In the south-eastern part of Mull a series of old volcanic rocks, alternating with breccias, conglomerates, and sandstones (all of later Palæozoic age), is exposed by the agency of great faults; while, at a great number of different points around the coast, strata of Middle and Lower Lias age are exposed beneath the lava streams, and are seen to rest unconformably upon the several palæozoic rocks; all these older formations are covered unconformably at some points by Cretaceous rocks representing the Upper Greensand and Chalk.

Wherever we approach the great central eruptive masses, whether of granite or gabbro, the whole of the stratified rocks, both of Primary and Secondary age, are found to have suffered great disturbance and intense metamorphism—the limestones passing into saccharoid marble, the sandstones into quartzites, and the shales into indurated slaty rocks or the "Lydian stone" of many old authors.

Lastly, as already noticed, fragments of nearly the whole of the underlying rocks of the island occur imbedded among the ashes, lapilli, and scoriæ forming the volcanic agglomerates already noticed.

4. *Sections illustrating the Structure of the Island of Mull.*—In consequence of the facility with which certain of the volcanic rocks of Mull yield to disintegrating forces, owing to their extremely

jointed condition, some of the mountains in the island present splendid natural sections, which afford the geologist the clearest insight into the relations of the different rocks which constitute them. By selecting several of these fine natural sections as types, we shall best be able to illustrate clearly the somewhat complicated relations of the different volcanic rocks of the island to one another.

a. Beinn Greig (see Section, Pl. XXIII. fig. 2) is a mountain which rises near the western end of Loch Bah to the height of 1941 feet. The appearance of this mountain, as viewed from the north, is very striking, the much-jointed granite and felsite which constitute the greater part of its mass having crumbled down, leaving an almost precipitous face. The lower and internal portion of the mountain, as is well seen on its south side, in the deep ravines which divide it from Beinn-y-chat and Beinn-a-Gobhar, is composed of a well-formed typical granite, for the most part of the hornblendic kind. As we ascend the mountain this granite is found to pass by insensible gradations into a quartziferous felsite, the hornblende being replaced by easily decomposable minerals, the decay of which greatly facilitates the disintegration of the rock. Still higher the rock becomes finely crystalline or granular, the magnesian and ferruginous materials being apparently no longer separately crystallized, but diffused through the mass as colouring-matters. The porphyritic structure is locally displayed by all portions of the mass alike, from the coarsest granite to the finest-grained felsite.

When the northern face of this mountain is viewed from a little distance, the whole mass presents the appearance of being made up of a number of concentrically curved beds. This pseudo-stratified appearance is, as all geologists are aware, very frequently presented by masses of undoubted igneous origin*; whether in the present example it is to be regarded as due to the manner in which the fluid rock was extruded, or to changes which have taken place in the mass during the process of cooling, I shall not here attempt to determine.

The granite and felsite of Beinn Greig are traversed by innumerable veins. These all appear to be of the "contemporaneous" class, and to be composed of similar materials to those of the mass itself, differing for the most part only in the degree of fineness of grain, colour, &c. Usually the rock of the veins is of much finer grain than that which it traverses; and in some analogous cases the acid rock actually passes into the glassy condition, and exists as pitchstone veins traversing granite. In a few instances thin veins of almost pure quartz and others made up of crystallized felspar are found.

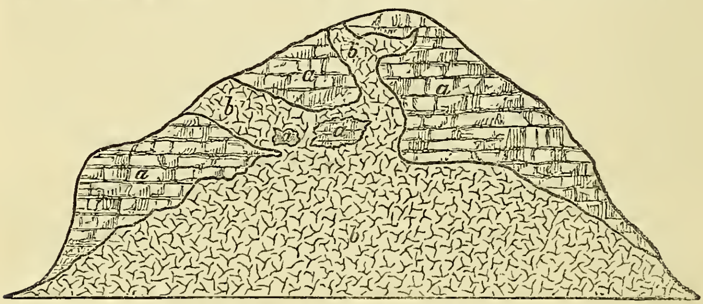
Lying upon the summit and flanks of the eruptive rocks just de-

* I may especially cite the granite of Arran, where similar features to those described as occurring in Mull were noticed by Macculloch. This concentric structure appears to be similar to that referred to by Mr. Scrope as occurring in certain of the domitic puys of Auvergne, such as Clierson and Le Grand Sarcouï (see 'The Geology and Extinct Volcanos of Central France,' 2nd edition, 1858, p. 68).

scribed, are sheets of lava of the highly acid variety (felstones), often highly vesicular and amygdaloidal in structure, which alternate with great masses of ash, lapilli, and scoriaceous fragments. The very rugged forms which these rocks assume in weathering causes them to present a marked contrast with the rocks on which they repose. They have evidently been thrust upwards to a certain extent by the great intrusive masses below them, and are seen dipping in both directions from them; on the west they are intersected by the shores of Loch-na-Kael, where their characters can be conveniently studied.

b. Beinn Uaig.—The relations of the intrusive granite and felsite to the overlying felstone lavas is, owing to the inaccessibility of many parts of the mountain, not conveniently exposed for study upon Beinn Greig. But in Beinn Uaig we have a precisely similar section in which the junction in question is beautifully illustrated. This section is represented in the woodcut, fig. 1. The granite and felsite

Fig. 1.—*Rocks forming the Summit of Beinn Uaig, Isle of Mull.*



a. Felstone lavas, with agglomerates.
b. Syenite-granite graduating into felsite.

are seen to give off great veins which traverse the masses of felstone lava and volcanic agglomerate, producing a very sensible degree of alteration in them along the surfaces of contact; and, further, these veins are seen to include masses of the traversed rock which have been caught up in them. In all these features we recognize the characteristics of intrusive granitic masses, which have been so admirably illustrated in the writings of Hutton, Playfair, Webb Seymour, and Macculloch.

c. *Craig Craggen* (Section, Pl. XXIII. fig. 3).—The valley of the Forsa or Pennygown river exposes on its western side a fine section of the mountain called Craig Craggen, which rises to the height of 1885 feet. We here find the granites and felsites presenting the same relations to the overlying felstone lavas as in the two examples before cited. As we trace the lavas up the slopes of the mountain the intercalated masses of agglomerate are found to become gradually thicker, until they constitute the larger portion of the mass, though still traversed throughout by lava sheets, and intersected by in-

numerable dykes. Associated with the agglomerates are numerous ejected blocks; these comprise examples of nearly all the rocks found beneath the lavas of Mull, including the Lower Silurian gneiss, quartzite, mica-schist, and slate, the Newer Palæozoic breccias, conglomerates, sandstones, and lavas, the Liassic rocks, and the Cretaceous quartzose conglomerates, grits, and sandstones.

At its northern end, as we approach the summit, the whole of the highly siliceous rocks which compose the mass of the mountain, granite, felsite, felstone lavas, and felspathic agglomerates, are seen to be penetrated indiscriminately by numerous intrusive sheets or dykes on the grandest scale, composed of various forms of gabbro, passing into dolerite and basalt, which have evidently produced a greater or less amount of alteration at the planes of contact in the rocks which they traverse. These great intrusive sheets and dykes of basic igneous rock were, from their position, evidently at one time connected with the great masses of gabbro forming Beinn Varnach and the eastern portion of Beinn Tsalla, from which they are now separated by the Forsa Glen. Owing to the manner in which these gabbro dykes resist denuding influences their course among crumbling rocks of the acid class can be easily traced by the geological observer.

The last point to be noticed with regard to Craig Craggen is that the spur known as Nid-a-shoag (the Hawk's nest) is capped by an isolated patch of ordinary basalt, which, from its amygdaloidal character is recognized as a portion of an old lava sheet; while, overlapping the felstone lavas, towards the northern foot of the mountain we find portions of the great series of basaltic lavas, which, though cut off abruptly on the shores of the Sound of Mull, are seen to be continued on the opposite side in Morvern. The relations of the several masses of rock of the basic class are such as to leave no room for doubt that the comparatively soft scoriaceous masses of this mountain owe their preservation to a covering of basaltic lavas, of which the outlier of Nid-a-shoag constitutes the last vestige; and it seems almost equally impossible to resist the inference that the lavas of the great basaltic sheets were once actually continuous with the great intrusive gabbro masses, which are composed of identical materials with them though in a different state of aggregation.

d. *Beinn More* (Section, Pl. XXIII. fig. 4).—To complete our series of illustrations of the relations which the several volcanic products of the island of Mull bear to one another, we cannot do better than notice this, the highest peak in the island. In the lower parts of this mountain and the spurs around it the granites, felsites, felstone lavas, felspathic agglomerates, with the intersecting dykes of gabbro, dolerite, and basalt may be observed presenting the relations to one another which have been already described. Resting unconformably upon these is a mass, many hundreds of feet in thickness and constituting the whole of the higher portions of the mountain, composed of basaltic scoriæ, tuffs, and ashes, alternating with lava sheets and intersected by a plexus of dykes. By the thinning-out of the masses of agglomerate the basaltic lavas come together, forming the great peninsula of the Bourg or Gribun, which is made up of lava sheets

piled on one another to the depth of more than 1600 feet. It is evident that the beds forming the summit of Beinn More, which are composed of alternations of lavas and agglomerates, the latter exhibiting in the fissures of ejected blocks so many beautiful minerals of the same kind as are found in similar positions in connexion with existing volcanoes, constitute the last vestige of a volcanic cone formed during the period at which the basaltic lavas were ejected. The entire absence of ejected blocks of the stratified rocks in these later agglomerates becomes a very significant fact when we remember that, while the earlier eruptions of acid rocks broke through masses of the older strata, the later basaltic masses forced their way through the midst of the former.

Although the great mass of the lavas constituting the great plateaux are of basaltic composition, yet they vary greatly among themselves in many minor features; and among them are occasionally found sheets of clinkstone*, a rock of a more or less acid or intermediate composition. The number of these exceptional lavas is found to greatly increase as we approach their points of origin, as in passing up Beinn More. This circumstance (one presented in many existing volcanoes) is easily explained by the well-known fact that the more acid lavas as a general rule exhibit a much less perfect fluidity than those of the basic class.

5. *Proofs that the Central Mountain-group in Mull constitutes the Relic of a great Volcano.*—No one familiar with the phenomena of active or recently extinct volcanoes, illustrated as these have been by the researches of Lyell, Darwin, Von Waltershausen, Humboldt, Von Buch, and many other investigators, but more especially by Scrope, in his classical work on 'The Geology and Extinct Volcanos of Central France,' can for one moment hesitate as to the interpretation to be given to the phenomena which I have described as being presented by the rocks of the island of Mull.

The group of mountains occupying the central portion of the island is clearly the greatly denuded core of an immense volcanic pile, the great accumulations of scoriæ and lavas which formed the bulk of this mountain-mass having been to a great extent removed, and what now remains to our study being little more than the skeleton or framework of the vast pile, formed by the consolidation of the springs of liquefied rock which rose through its mass. "If," wrote the late Professor Jukes, "we could follow any stream of lava to its source in the bowels of the earth, we should probably find it changing, under varying circumstances of depth and pressure, from scoriæ or pumice to granite"†. By the study of the relations of the rocks of Mull the geologist is able to supply the most complete verification of this conclusion, and indeed to illustrate every stage of the transformation.

* The term "porphyrite" has been sometimes applied to these rocks; but they agree in every essential respect with many of the phonolitic lavas of recent volcanoes. Rocks precisely resembling those of Mull occur in the central masses of Mont Dore and the Mezen in Central France.

† Encyclopædia Britannica, Art. "Mineralogy and Geology."

Moreover the history of the accumulation of its materials, the plan of its architecture, and the succession of the changes which have taken place during its formation may be distinctly read in the ruins of this old volcanic cone.

At the commencement of the Tertiary Period the area now constituting the island of Mull formed part of an old land-surface composed of many different rocks. It is not difficult to reconstruct the geological features of the district at that period. Strata of Laurentian age were covered unconformably by highly metamorphosed Lower Silurian rocks, through the midst of which arose a great eruptive mass of granite. Lying unconformably upon the Older Palæozoic rocks were great masses of old lavas &c. belonging to the Newer Palæozoic periods, while the whole was unconformably overlain by many patches of Jurassic strata. Lastly, overlapping the whole of the rocks already noticed, and lying upon their upturned and denuded edges, were a number of tracts composed of Cretaceous rocks only recently upheaved above the sea-level.

Such were the geological features of the land upon which the grand and long-continued series of volcanic phenomena which we have to describe were displayed. This volcanic action appears to have commenced by the opening of vents from which violently escaping steam hurled aloft great volumes of felspathic ashes, lapilli, and scoriæ, mingled with numerous fragments torn from the rocks through which the explosive discharges took place. These eruptions of fragmentary matters were accompanied, at intervals, by the outflow of streams of acid or trachytic lavas now forming felstones. And, further, the rising liquid mass from which these streams were fed, to a certain extent forced upwards the rapidly accumulating deposits of ejected materials, injecting at the same time with its substance the numerous fissures which the expansive force could not fail to create in the superincumbent and surrounding rocks*. By slow consolidation under pressure the fluid matter gave rise to the formation of masses and veins of felsite and granite. Thus there was gradually built up a great volcanic pile, composed principally of igneous materials of the acid variety.

This period of the ejection of acid materials, which was doubtless one of vast duration, appears to have been followed by one of inactivity; for there is distinct evidence that before the second series of eruptions took place the first-formed cone had undergone great decay: explosions had destroyed its symmetry; subsidences had taken place in portions of its mass; and denudation had removed to a large extent its covering of agglomerates and lavas, exposing the granites and felsites of its central mass.

The second period of eruption was marked by the prevalence of

* Whether some of the granitic and felsitic hills of Mull are the centres of great masses of acid lavas, extruded in a bulky form at the surface, like the "domitic puys" of Auvergne, the central trachytic masses of Rocca Monfina, or the bosses in the midst of the crater of Astroni, it is not possible, in the present degraded condition of the Mull volcano, absolutely to determine. From the analogy of the cases we have cited and also many similar ones, however, we may reasonably infer such to have really been the case.

materials of the basic class among the products of this volcano. The liquefied materials of this period were forced through the older igneous rocks, fissuring them in every direction: those fissures which did not reach the surface would be filled by the consolidating rock and form dykes; but, doubtless, many of these great rents extended to the surface and then gave rise to those eruptions producing the "parasitic cones" so common on the flanks of many great volcanoes. The lavas of this period being possessed of so much greater fluidity, instead of being confined, like those of older date, to the neighbourhood of the volcano, flowed to enormous distances; and so vast were the volumes of material discharged from the volcano, that the lava streams accumulated to a thickness of 2000 feet. That the formation of deposits of such vast thickness occupied periods of enormous duration we may reasonably infer; and the conclusion is confirmed by the proofs of intereruptive denudation among these old lavas, and by the existence of old soils, forest-growths, river-gravels, and lacustrine deposits between them.

At the close of this second period of eruption the volcano of Mull became extinct, and has gradually fallen into that state of decay and ruin which it now presents. But, as we shall hereafter show, volcanic activity in the district did not cease with the extinction of this and the other similar great volcanic mountains of the period.

Having demonstrated the real nature of the central mountain-group in the island of Mull (namely, that it constitutes the basal wreck of a great volcanic pile), I shall proceed to show that, at a number of other points in the same district, there occur similar masses of eruptive rocks associated with volcanic agglomerates and breccias, and that these are the relics of other volcanoes, similar to, and contemporaneous with, that of Mull. After the details into which I have entered with regard to this last-mentioned example, it will not be necessary for me to do more, in describing the other similar instances, than to point out in a general manner the analogies and variations of their structure as compared with that which we have chosen as the type.

6. *The Volcano of Ardnamurchan.*—Immediately to the northward of the island of Mull stretches the peninsula of Ardnamurchan, which forms the most western portion of the mainland of Scotland. In this district we have exhibited to us, though in a much more fragmentary condition, a precisely similar series of rocks, presenting relations with one another identical with those described in the island of Mull.

Constituting the peak of Meal-nan-con and a number of adjoining heights, which stretch in a belt south-westward to near Kilchoan, we find great masses of intrusive felsite presenting many local variations, but as a whole exhibiting a striking identity with the great felsitic rocks of Mull, like which they, in places, assume a distinctly granitic character. Lying upon the eastern and southern flanks of these felsites and penetrated by numerous veins which proceed from them are numerous sheets of felstone, often of amygdaloidal structure. These are interstratified with beds of ash

and scoriæ, enclosing fragments of the Lower Silurian and Jurassic rocks which constitute the foundation on which the volcanic rocks of Ardnamurchan are piled.

The whole of the western extremity of the peninsula of Ardnamurchan is constituted by masses composed of many varieties of gabbro, which form a number of wild and barren mountains. At the western extremity of the peninsula the pyroxenic ingredient of the gabbro is either diallage or hypersthene; but as we go eastward these are found to be replaced in varying degrees by other members of the pyroxene family, and the gabbro graduates into dolerite.

Of the intrusive character of this great mass of highly crystalline basic rocks, and its posteriority alike to the Secondary strata and the felstone lavas and felsites, we have the most ample proof. Along the southern side of the peninsula, on either side of the cape called Stron Beg, the strata of Lias and Inferior Oolite are seen to be upheaved at very high angles on the flanks of the masses of gabbro; and as we approach the latter the sedimentary deposits are found to undergo the most wonderful metamorphism; sandstones are seen passing into quartzites, limestones into marble, and clay into hard shale, slaty rock and "Lydian stone." Not less striking are the effects produced by the gabbros on the earlier volcanic rocks, the felstone lavas which overlie the Secondary strata. In proximity to the gabbros, these felstone lavas are seen to have been upheaved at high angles and to have acquired a peculiar platy structure and splintery fracture, combined in many cases with the development of a probably preexisting banded coloration. Even the crystalline felsites have not escaped the general metamorphism, but exhibit peculiarities of texture and fracture near their junction with the gabbros.

Secondary strata, felstone lavas, and felsite masses are alike penetrated in all directions by innumerable veins, dykes, and sheets of gabbro, dolerite, and basalt; while, to the eastward, the vestiges of old basaltic lava-flows are seen resting indifferently upon the Lower Silurian gneiss, the Secondary strata, and the felspathic lavas of the earlier period of eruption.

Here then, in spite of the more fragmentary character which the relics have assumed in consequence of the enormous amount of denudation which they have suffered, their analogy with the rocks of Mull is unmistakable and points to precisely to the same succession of events. It is evident that in Ardnamurchan we have preserved the "sector" of a great circular volcanic pile, which, like that of Mull, consisted of an older interior mass composed of igneous rocks of the acid class, intrusive, laval, and fragmentary, which mass was pierced and enveloped by the basic products of a second period of eruption.

The manner in which, by means of denudation, the internal structure of the volcanic masses of Ardnamurchan has been laid bare to our view in sea-cliffs and deep ravines, renders this fragment of a volcano of special interest to the geologist. Here he is

enabled to study in detail the results of the potent subterranean actions which went on side by side with those subaerial phenomena with which our ideas of volcanic activity are usually associated, but which do not constitute the only, nor perhaps even the principal effects of these grand outbursts. To the consideration of these subterranean phenomena I shall have to return in the sequel.

7. *The Volcano of Rum.*—Lying to the north-west of the peninsula of Ardnamurchan we find the group of the Small Isles, comprising Rum, Canna, Eigg, and Muck, with several smaller islets. The whole of these, with the exception of the first mentioned, are evidently isolated fragments of a plateau composed of basaltic lava-sheets, which are in some places seen to rest unconformably upon various Secondary strata. In the island of Rum, however, we find a great mass of eruptive crystalline rocks which have burst through the older strata; and the various igneous products, in their nature, positions, and relations, present such remarkable analogies with those of Mull and Ardnamurchan as to leave no room for doubt that in Rum also we have the basal relics of a great volcanic mountain (Section, Pl. XXIII. fig. 5).

Nothing can be more instructive than the admirable manner in which, through denudation, the mutual relations of the stratified and eruptive rocks are displayed in the island of Rum. The former consist of Cambrian sandstone with some masses of gneissose, schistose, and quartzose rocks, probably of Lower Silurian age; these occupy the north-west, north-east, and south-east sides of the island, while its interior is formed by masses of eruptive rocks, including both granites and gabbros, which rise into lofty mountains. At a distance from the igneous rocks, the Palæozoic strata exhibit their usual mineralogical characters and their normal strike and dip; but wherever they approach the great central intrusive masses they are found to be violently upheaved and often much contorted, and are further seen to have undergone a striking metamorphism, which often extends to a considerable distance from the igneous rocks; the more argillaceous or felspathic portions of the Cambrian sandstone pass into a highly micaceous black schist, and the more siliceous portions into an impure quartzite. The whole of the stratified rocks surrounding the intrusive masses of granite and gabbro are intersected in all directions by innumerable veins and dykes.

Let us now turn our attention to the igneous masses which form the central group of mountains, and upon the flanks of which the Primary strata lie on three sides of the island, having evidently been removed by denudation on the fourth side. These central mountains of Rum, as is evident to the most casual observer, are composed of two very distinct kinds of rocks, the contrast between which, owing to their different modes of weathering, is extremely striking.

To the westward, and forming the smooth dome-shaped mountain mass of Oreval (1872 feet) and its dependencies, is a great development of much-jointed highly felspathic rocks, consisting of granite

passing by every gradation into felsite. These rocks are identical in all their characters with the acid rocks of Mull. They occur also in the south-east of the island of Rum, being there, however, much broken up by numerous sheets and veins of the crystalline basic rocks.

The north-eastern mountains of the central group rise into singularly wild and rugged peaks, among which are Haskeval (2667 feet), Halival (2367 feet), Scùr-na-gilean (2553 feet), and Beinn More (2505 feet). They are composed of the varieties of gabbro in which the pyroxenic constituent consists of several varieties of the augite group, but in which diallage and hypersthene only rarely occur. Precisely similar rocks are found, as we have seen, forming the outer portions of the great basic intrusive masses and the veins which proceed from them, both in Mull and Ardnamurchan. The great masses of gabbro in Rum often exhibit that pseudo-stratification so often observed in igneous rocks, and of which we have noticed such a remarkable example in the granites and felsites of Mull. They are also penetrated by numerous "contemporaneous veins."

The relations between the eruptive masses of the acid and basic classes respectively are scarcely less strikingly displayed in Rum than in Mull; we find numerous offshoots and veins proceeding from the gabbros and traversing the granites and felsites, as well as the surrounding older strata and the agglomerates and lavas.

Thus the island of Rum is for the most part made up of great intrusive masses, and of the more or less disturbed and altered sedimentary deposits through which these have been thrust. Of the overlying ejected materials (lavas, scoriæ, ashes, and breccias) only comparatively small and isolated vestiges remain; owing, however, to the clear manner in which the relations of these to the other rocks are displayed, they are well worthy of attentive study by the geologist.

On the northern flanks of the mountain of Halival we find a great mass of felstone lavas intermingled with agglomerates. But associated with these are deposits of enormous thickness, consisting of blocks of Cambrian sandstone of all sizes imbedded in a matrix of felspathic ash. The included blocks of sandstone in this volcanic breccia vary greatly in size, from masses several feet in diameter down to the smallest fragments. As we approach the gabbro masses which form the bulk of the mountain, the felstone lavas are seen to undergo analogous changes to those manifested in similar positions by the same rocks in Ardnamurchan and Mull.

Other patches of felstone lavas with accompanying agglomerates, which have escaped destruction by denudation, occur at several points on the south-eastern side of the island. On the western side, however, there are several small outliers of the ordinary columnar and basaltic lavas. These exhibit all the usual characters of the sheets forming the great plateau, and were doubtless once continuous with the other and larger outliers of the same rocks, which constitute the islands of Canna, Eigg, and Muck. At Scùr More, or

Bloodstone Hill, these rocks present some features of interest to the mineralogist, owing to the beautiful specimens of heliotrope and other minerals which are found in their amygdaloidal cavities.

But to the geologist the fact of greatest interest in connexion with these basaltic lavas is that they rest directly upon the granite and the Cambrian sandstone, thus affording a most striking proof of the unconformity which exists between the products of the two great periods of volcanic eruption, and an indication that a vast interval must have elapsed between them. This is plain from the fact, of which we have clear evidence, that rocks of the acid class were much wasted by denudation before being covered up by the ejection of basaltic materials.

It is unnecessary for me to remark on the striking manner in which the peculiar features and relations of the rocks of Mull and Ardnamurchan are, in every essential detail, repeated in those of Rum; nor is it necessary to insist upon the conclusion that, like the examples before described, these rocks must be regarded as the relics of a great volcanic pile, and the products of a similar succession of eruptions.

8. *The Volcano of Skye.*—It is doubtless a misfortune that the attempts to unravel the somewhat complicated phenomena presented by the igneous rocks of the Hebrides have hitherto, for the most part, been made in the most frequently visited island of the group, Skye. For, although the relations of the rocks of this island are sufficiently clear, when viewed in connexion with the analogies presented by the other islands; yet, considered alone, they are by no means obvious. It is not surprising therefore that observers, unacquainted with the clearer sections of Mull, Ardnamurchan, and Rum, should have been sometimes led to conflicting conclusions upon the subject.

I will in the first instance point out briefly in how exact a manner all the essential and distinctive features of the old volcanoes already described are repeated in that portion of the island of Skye which is included between Loch Sligachan and Broadford Bay on the north, and Lochs Brettle and Eichart on the south.

Nearly the whole of this district is composed of intrusive rocks which have burst through strata of Palæozoic (Cambrian and Lower Silurian) and Mesozoic (Liassic and Oolitic) age: these are seen at a number of points lying in a greatly disturbed and hightly metamorphosed condition upon the flanks of the igneous masses.

These igneous intrusive masses consist of two different kinds of crystalline rocks, granite and gabbro; and the contrasts between their modes of weathering are exhibited in their most exaggerated form in the island of Skye. The granitic masses of the Red Mountains, culminating in Beinn Glamaig (2670 feet) and Beinn-na-Cailleach (2385 feet), are as remarkable for their strikingly smooth pyramidal forms as the gabbro masses of the Cuchullin Hills and Beinn Blabheinn (both exceeding 3000 feet in height) are unrivalled for their wild, jagged, and fantastic outlines*. The granites of the Red Mountains graduate into many varieties of felsitic rocks,

* *Vide* Geikie, 'Scenery of Scotland,' pls. 2 & 4.

and are traversed by numerous "contemporaneous veins," usually of similar composition to the mass which they traverse; the gabbros of the Cuchullin Hills and Blabheinn pass insensibly into dolerites and basalts, and are also traversed by many "contemporaneous veins." Both of these intrusive rocks, in places, exhibit the pseudo-stratified appearances so commonly displayed by igneous masses.

That the rocks of basic composition were ejected subsequently to those of the acid variety, is illustrated by sections at a number of different points; and this fact was detected by the late Principal J. D. Forbes * in 1845, and by Professor Zirkel † in 1868.

As in Rum, the ejected rocks, lavas, agglomerates, and breccias form only disconnected outliers in Skye; but some of these present very interesting characters. Patches of volcanic agglomerates and breccias, including fragments of the several Primary and Secondary rocks through which this volcano has burst, are found at several points: the preservation of these is probably due to local subsidences; and a good example of them may be examined in the hill on the south of Beinn Dearg, known as Cnoc-na-Fitheach. Outliers of the felstone lavas, more or less mingled with scoriæ and ashes, occur at a number of points round the central mountain-group, and in the island of Scalpa and the peninsula of Strathaird are seen lying directly upon the various Primary and Secondary strata.

Of the great basaltic plateaux which doubtless once surrounded the old volcano of Skye on all sides, we have also only a number of fragments left. By far the largest and most important of these is the one which, stretching north-westwards, constitutes the great peninsulas of Trotternish, Vaternish, Durinish, and Minginish. This mass of lavas has been upheaved on its eastern side so as to display in a very interesting manner the Secondary rocks upon which it lies. Another small outlier of the basaltic plateaux, which has escaped from destruction by denudation, occurs in the adjacent island of Raasay, where it forms the highest point, the striking hill of Dun Can. In Applecross, however, denudation has proceeded one step further, the lava streams having been altogether removed, and thus the Secondary rocks with their included sheets of intrusive igneous rock exposed at the surface. Further, for great distances round the central mountain-group of Skye the whole of the stratified rocks are penetrated by innumerable dykes and intrusive masses both of acid and basic composition.

9. *The Volcano of St. Kilda.*—I have not yet been able to visit this remote group of islands; but from the descriptions of Martin and Macculloch it is sufficiently obvious that we have in them the relics of another of the old Tertiary volcanoes. The islands are said to consist wholly of "trap-rocks;" and the central and largest of the group is described as being formed in its eastern part of granite, and in its western part of gabbro. Macculloch, who was so competent a judge of petrological characters, informs us that these rocks were identical in every respect with those found in the island of Rum.

* Edinb. New Phil. Journ. New Ser. vol. xl. (1845–46), p. 86.

† Zeitschr d. deutschen geologischen Gesellschaft, Jahrg. 1871, p. 90.

10. *Comparison of the great Tertiary Volcanoes.*—It has been shown in the preceding pages that we have evidence of the existence during the Tertiary period of five great centres of volcanic action in the northern portion of the Hebrides—and that at each of these points a great volcanic mountain once existed, the fragmentary, but unmistakable, relics of which still remain for our study. A problem which, however, will naturally suggest itself to every mind is that of the causes which have led to the very different states of preservation of volcanoes which appear to have been formed contemporaneously. The portion of this inquiry which is of more especial interest to the geologist is that concerning the reasons of that comparatively perfect state of preservation exhibited by the volcano of Mull which renders it so admirable a key to the interpretation of the whole series of phenomena presented by the Western Isles of Scotland.

Fortunately the causes of the different extent of denudation in the several cases, and of the exceptional state of preservation of the volcano of Mull, are sufficiently obvious; and as the consideration of these leads us to some highly interesting and important conclusions, I shall now proceed to detail them.

If we compare the volcanoes of Mull and Skye, the differences alluded to, in spite of the identity of the characters and relations of the various rocks which compose them, are very striking. Thus while in the former case we observe the most wonderful interlacing of the two kinds of eruptive rock, and the outliers of the great superposed piles of fragmentary materials are still clearly to be traced, in the latter case the two great eruptive masses rise side by side, with but comparatively few examples of offshoots from the younger into the older series, and the lavas, agglomerates, and breccias which formed the mass of the volcano have almost wholly disappeared.

A careful study of the rocks of Mull shows the cause of this difference to be that the volcanic pile in this island has suffered far less from denudation than in Skye, and that in fact the existing surface in the former island presents a cross section of a volcano taken at a higher level than in the latter. Further, it can be shown that this difference is due to a remarkable central subsidence which has taken place in the case of the Mull volcano.

When we examine the fine sections of the lavas of the basaltic plateaux which are exposed along the shores of the deep fiords of Loch Scridain and Loch-na-Kael, we find that the lava sheets, instead of sloping away from the great central masses of eruptive rock, actually for many miles around dip *towards* them at angles varying from 2° or 3° up to 5°, the inclination increasing as we approach the volcano. Now, as we are certain that this was not the original position of the lava streams, we are led to the conclusion that a subsidence has taken place in the great central mass of the island, a view which is confirmed by an examination of the inclination of the whole of the lavas surrounding the volcano. Still further support to the inference is afforded by the fact that at certain points, as in the valley between Kilfinichan and Gribun, where the Cretaceous rocks under-

lying the lavas are suddenly cut off, we have clear evidence of the existence of faults the downthrow of which is in all cases towards the great central mass.

By a study of the section of Craig Craggen in connexion with those exposed at some other points, we are led to infer that a similar subsidence took place after the period of the eruption of the acid lavas, and before the outpouring of the basaltic lavas from the same centres commenced.

Now it is a most interesting fact that precisely similar subsidences beneath cones of comparatively recent date have been shown to exist in the case of a volcano in the Cape-Verde Islands by Mr. Darwin *, and in one in New Zealand by Mr. Heaphy †. The phenomena described in these two modern examples are perfectly analogous to those presented in the ancient volcano of Mull; indeed Mr. Scrope has, in reasoning on the causes of the phenomenon, speculated on the probability of its very general occurrence to a greater or less extent in the case of many volcanoes ‡.

According to the observations of Krug von Nidda, Iceland exhibits a precisely similar subsidence of the great volcanic centres to that which we have been describing in Mull, and on even a grander scale §.

From the relative positions of the central masses of granite and gabbro in the great Tertiary volcanoes of the Hebrides we are led to infer that changes must have taken place in the position of the axes of eruption of several of them in the same manner as has been so admirably illustrated in the case of Etna by Sir Charles Lyell (*vide* Phil. Trans. for 1858, pp. 738–744, and 'Principles of Geology' 11th ed. vol. ii. pp. 9–14).

With the consideration of the causes of the phenomenon of the central subsidence of volcanic piles, however, we are not here concerned; but its effect in the island of Mull, where it is exhibited in so marked a manner, has been the exceptional preservation of a series of rocks which afford us the clearest insight into many important matters connected with the history of these ancient volcanoes.

I have already had occasion to allude incidentally to the wild and rugged character of the scenery to which the basic crystalline rocks

* Volcanic Islands, p. 9.

† Quart. Journ. Geol. Soc. vol. xvi. (1860) p. 244.

‡ Volcanos, 2nd edit. (1872) p. 225.

§ Karsten's Archiv, vii. (1834) pp. 247–284. Recent studies of the positions and relations of the older volcanic rocks of the Lipari Islands have convinced me that similar central subsidences must have taken place in connexion with the great volcanic piles of that area. It seems not unreasonable to suppose that the deflection of the liquefied matter below a volcanic centre to new vents may very generally give rise to a certain amount of subsidence in the masses of ejected materials which, often to a very great height, have been piled about it; the great weight of the latter would assist in producing the same result. Of course such gradual and comparatively slight subsidences will not be confounded with, or thought to lend any countenance to, the theory of violent engulfment of the central parts of volcanic mountains, to which cause some geologists have felt disposed to refer the formation of their great crateral hollows.

of the Western Isles give rise, owing to their peculiar modes of weathering. Acted upon very slowly by the agents of atmospheric disintegration, the rock-surfaces assume a remarkable roughness owing to the persistence of the crystals of diallage and augite, acquiring at the same time a deep brown tint from the peroxidation of the iron; and, moreover, these surfaces, not giving rise to the formation of soil, are altogether destitute of any covering of vegetation. The lower flanks of the mountains are marked by the dome-shaped forms resulting from the passage over them of glaciers; and the grooving and striation are wonderfully preserved upon them*; but the summits of the same mountains stand up in the form of wild craggy pinnacles, many of which are altogether inaccessible. Moreover the striking features of these rugged and barren rocks are heightened by the contrasts which they present with the verdant, terraced slopes of the basaltic plateaux on the one hand, and the smooth, dome-shaped and débris-covered hills of granite on the other.

These features of the gabbro rocks are displayed in a sufficiently striking manner in Mull, especially in the wild glen between Beinn Buy and Creach Beinn, and also in Ardnamurchan and Rum; but in each of these cases the entangled portions of acid rocks give rise to the formation of streams and taluses of detritus and the consequent production of soil and vegetation, relieving the monotonous barrenness of the surfaces of these rocks. But in the island of Skye we have a considerable area which is formed almost exclusively of the gabbro rocks; and the wonderful features of the scenery to which these give rise are familiar to all who have visited the Cuchullin Hills and Blabheinn, being most remarkably displayed in the sombre glen which contains the "dark loch" of Coruiskh.

The deep impression made by this remarkable scene on the mind of Sir Walter Scott is recorded in his well-known lines in the 'Lord of the Isles':—

"Rarely human eye has known
A scene so stern as that dread lake,
With its dark ledge of barren stone.
Seems that primeval earthquake's sway
Has rent a strange and shattered way
Through the rude bosom of the hill,
And that each naked precipice,
Sable ravine, and dark abyss,
Tells of the outrage still."

But for the geologist this justly celebrated, and now tourist-haunted, locality may claim a more especial interest. For if his study of the rocks dispels, as it certainly will do, the poet's beautiful dream concerning their origin, it will be only to replace it by a far grander conception; and as he stands here, in the very centre of the cooled reservoir of an ancient volcano, his instructed imagination will revel in the reconstruction from reliable data of the wild and grand features of this old "Tierra del Fuego."

* *Vide* J. D. Forbes, Edinb. New Phil. Journ. New Ser. vol. xl. pp. 90–99 (1845–46).

11. *Dimensions of the great Tertiary Volcanoes.*—It might at first sight appear impossible to arrive at any sound conclusions upon this question, concerning, as it does, the physical features of a period so remote from the present. Nevertheless, as I hope to be able to show, so far is this from being the case, that we have several different kinds of data, foremost among which must be ranked those derived from the subsidence which we have shown to have taken place in the case of the Mull volcano, enabling us to arrive at least at an approximate estimate.

We are able in the case of each of the great Tertiary volcanoes to to arrive at some idea concerning the areas covered by their bases. The base of the volcano of Mull must have had a circumference of at least forty miles; Etna, which has a greatly truncated form, nevertheless rises to the height of 10,900 feet from a base only thirty miles in circumference*; a similar relation between the base and altitude of the great volcanoes of Sicily and Mull would lead us to infer that the elevation of the latter was at least 14,500 feet.

By a careful study of the present inclinations of the lava streams which flowed from the Mull volcano, we may obtain another approximation to the minimum possible elevation of its summit. From an examination of all the data, especially those furnished by the sections along the shores of Loch Scridain and Loch-na-Kael, and carefully availing myself of every check in making the calculations, I find that, if the rocks were restored to the positions which they occupied before the great central subsidence took place, the present summit of Beinn More, which is 3172 feet above the sea, would be raised to to an elevation of at least 6000 feet—and, further, that a central cone reconstructed on the basis thus obtained would have an elevation of more than 10,000 feet.

But this must be regarded as only the lowest possible estimate; for in making it I have totally neglected four different considerations, all tending to increase our estimate, but by what exact amounts it is impossible to state. These are:—

(1) The gradual increase of the inclination of the lava-beds on the higher slopes of the mountain.

(2) The effect of the great faults before alluded to as contributing to the central subsidence, the influence of which, though not exactly determinable, was certainly very considerable.

(3) The originally greater elevation of the surfaces on which the volcanic rocks lie. This is proved by the fact that many rocks which were certainly of terrestrial origin are now below the sea-level.

(4) The great masses of agglomerates and lavas which originally formed the summit and flanks of the mountain, but have now been removed by denudation.

In speaking, however, of the height of a volcano it must be remembered that we are dealing with a quantity subject to constant and wide variations. During a single paroxysm, hundreds, nay, even thousands, of feet of materials may be blown from the sum-

* In this estimate I of course only include the mass of rocks constituting the mountain proper, and not the lava-covered plains around it.

mit of a volcano, and in a few days, weeks, or months a new cone of different form and proportions built up. Such changes doubtless occurred over and over again in the case of the ancient volcanoes of Scotland as well as in those of more recent date.

From the area which its relics occupy, we may conclude that the volcano of Skye was not inferior in its dimensions to that of Mull; and on similar grounds we are led to infer that the volcanoes of Rum, Ardnamurchan, and St. Kilda, though somewhat smaller than these, were nevertheless mountains of great extent and elevation.

Thus we are led to the conclusion that during the Tertiary epoch there existed in the north-western part of the British Islands a range of volcanic mountains which were on the grandest scale—a fact which all who consider the wonderful extent and thickness of their accumulated lava streams will be fully prepared to admit.

12. *Series of later Volcanic Eruptions in the Hebrides resulting in the formation of "Puys."*—I shall now proceed to show that, subsequently both to the period of the eruption of the acid lavas and to that of the ejection of basic rocks, and at a time when the great volcanoes from which these flowed had become extinct and their products greatly denuded, another series of volcanic outbursts of a sporadic character took place within the district, and gave rise to the formation of numerous smaller cones with their accompanying lava streams.

The researches of Mr. Scrope in Central France, of Mr. Darwin in the volcanic islands of the Atlantic, of Hamilton and Strickland in Asia Minor, with others that might be cited, have sufficiently demonstrated that the extinction of great volcanoes is in many (if not in all) cases followed by eruptions on a minor scale, which burst out in the plains at their base and give rise to the formation of numerous small cones, usually arranged along what appear to be lines of fissure. It would seem that the volcanic forces having to a great extent expended themselves, and being insufficient to raise columns of lava to the summits of the mountains which successive eruptions have continually elevated, have nevertheless been able, before sinking into absolute quiescence, to open new vents at lower levels. To the class of smaller volcanoes thus produced it will be convenient to apply the general term "puys,"* from the name by

* It is of course impossible to draw any absolute line of demarcation between the class of subsidiary or parasitical cones which are so abundant on the flanks of many great volcanoes (on Etna there are said to be no less than 800 of them) and that of the "puys," or cones thrown up in the plains in their vicinity. As is so well shown by Mr. Scrope, in his work on Central France, the formation of such puys in a district may be going on during periods of vast duration, and the several eruptions to which they owe their origin may be separated by very wide intervals of time. They appear, however, in almost all cases to be of subsequent date to the extinction of the great central volcanic mountains, and sometimes, indeed (as in the case of the Puy de Tartaret in the Mont Dore), to have been formed in the midst of the ruinous masses of rocks to which such great volcanoes have been reduced by denudation. The course of events in connexion with the history of the decline and decay of a great volcano would appear to be

which they are known in the district rendered classical by the admirable researches and descriptions of Mr. Scrope. I shall now proceed to describe the remarkably interesting evidences which remain of the former existence of such "puys" in connexion with the great volcanoes of the Hebrides.

In the peninsula of Ardnamurchan the highest mountain, Beinn Shiant, rises to the height of 1759 feet. Its very peculiar outlines (see woodcuts figs. 2 & 3, p. 262), exhibiting neither the terraced slopes of the masses composed of superposed lava streams, nor the peculiar contours of either of the two classes of eruptive rocks, are alone sufficient to arrest the attention of the geologist and to lead him to its careful examination. And such study is amply rewarded. The mountain, which exhibits a series of grassy slopes reaching almost to its summit, is remarkable for the far-stretching and boldly shaped spurs which on all sides branch out from a common centre. On a nearer approach we find the cause of these striking features to be that each of the spurs is capped by masses of lava usually exhibiting beautifully columnar forms, while the green slopes below are composed of softer and more easily weathered rocks. The mountain rises near the line of junction of the older felspathic and basaltic lavas before described.

The lavas of Beinn Shiant are intermediate in character to the acid and basic rocks which constitute the masses of the older and great central volcanoes; they present distinctive features by which they are easily recognizable, and are remarkable alike for their great hardness and their power of resisting atmospheric denudation. They constitute rocks of great beauty, varying from aggregates of crystals of glassy felspar, through numerous porphyritic and highly crystalline varieties to compact felstones, which finally pass into pitchstones of more or less porphyritic character, these last being sometimes identical in their mineralogical features and the peculiarities of columnar structure with the rock of the well-known Scùr of Eigg. These lavas appear to be very similar in character to a dark-coloured porphyritic trachyte which occurs at Mont Dore les Bains in Auvergne*.

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generally as follows:—By constant ejections from its summit a volcano is continually increasing its height and adding to the length of the column through which fluid materials must be raised in order to produce a central eruption. In the course of this action a point will certainly be arrived at when it becomes easier for the subterranean forces to rend new fissures in the flanks of the mountain than to raise a column of lava to its elevated summit. At this stage of its history Etna now appears to have arrived, the formation of new parasitical cones on its flanks alternating with comparatively feeble ejections from its summit. But, as the bulk and solidity of a volcanic cone are continually added to by these operations, the subterranean forces will be gradually forced to seek new vents at lower levels in the plains around the mountain, and thus give rise to the formation of "puys." In Ischia, the Lipari Islands, and many other volcanic districts, we have admirable opportunities afforded to us for tracing the sequence of this very interesting series of operations.

* In the islands of Lipari and Salina we have many beautiful illustrations of lava streams, composed of dark-coloured, often nearly black, trachyte, with disseminated crystals of sanidine. These rocks are precisely similar to those

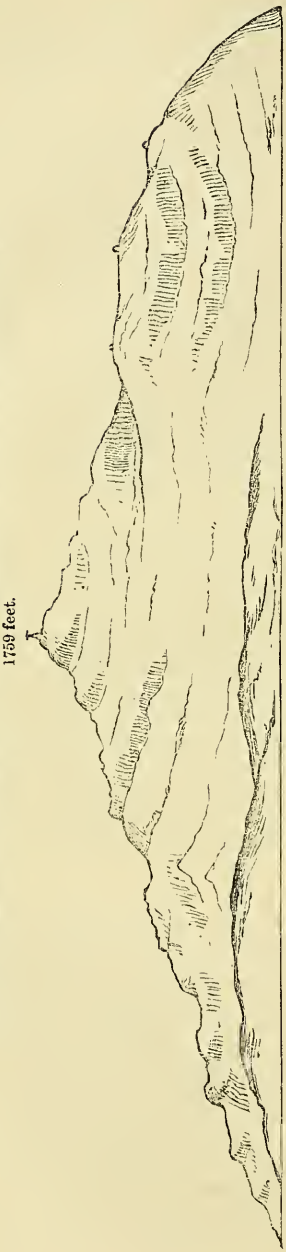

Fig. 2.—*Outline of Beinn Shiant, in Ardnamurchan, as seen from the N.N.W.*

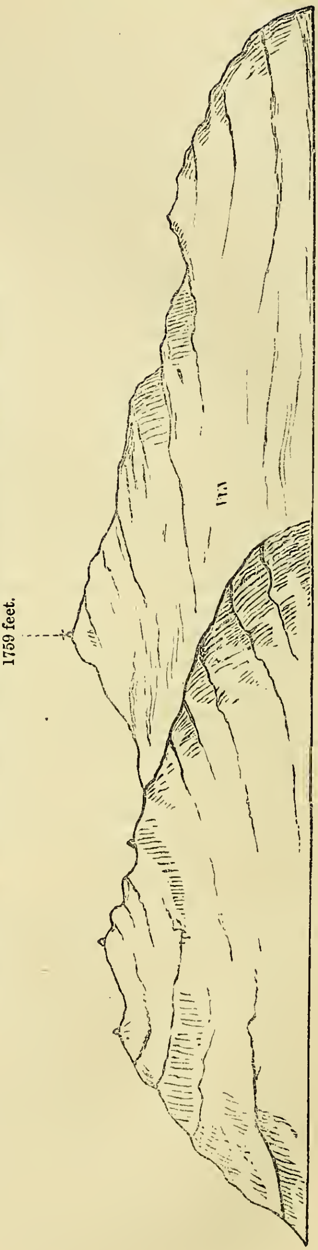

Fig. 3.—*Outline of Beinn Shiant, in Ardnamurchan, as seen from the W.*

The central and apical portion of the mountain of Beinn Shiant is formed of rocks of similar petrological character, which, however, are apparently of intrusive origin. On the northern side of the mountain these rocks form a lofty and precipitous ridge.

The masses of columnar rock evidently constitute portions of a number of lava streams which appear to have been originally in connexion with the central mass, and to have diverged in a radial manner from it. Some of these lava streams can be traced to very considerable distances.

Where the grassy slopes below the lava cappings of the spurs are cut through by streams, they are seen to be composed of volcanic agglomerates and breccias. These contain numerous angular fragments of both the felspathic and basaltic lavas of earlier Tertiary periods with some of the underlying Lower Silurian gneiss, such being the rocks upon which the mass of Beinn Shiant is built up; mingled with these are numerous fragments of felspathic scoriæ and ashes, with many fractured and worn crystals of glassy felspar included in the mass*.

Fortunately for the geologist, one of the spurs of Beinn Shiant is cut across in a sea-cliff forming the headland of Srone More or Maclean's Nose; and here we have a magnificent display of the wonderfully interesting features in the rock-masses composing this remarkable mountain. The upper part of Srone More, which rises to a height of 1050 feet, is composed of the columnar lavas already described; but the almost precipitous cliffs below are seen to be made up of nearly angular blocks of all sizes, up to 6 or 8 feet in diameter, heaped together in the wildest confusion, and presenting no appearance whatever of stratification or of the sorting of the materials according to their specific gravity.

Lastly, it is necessary to notice that the great masses of agglomerate which constitute so large a portion of Beinn Shiant, together with the older lavas and gneiss on which they are piled, are traversed in every direction by dykes and veins of every size, composed of similar rocks to those forming the lava streams—namely, trachyte and "pitchstone-porphyry."

To any one familiar with the characters presented by Arthur's

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of Beinn Shiant, and like them graduate, in consequence of the matrix in which the felspar crystals are imbedded acquiring a glassy texture, into "pitchstone-porphyry." In speaking of the Eocene acid lavas of the Hebrides, I have preferred to apply to them the term "felstone," although it must be remembered that they present no *essential* points of distinction from recent quartz-trachytes, either in chemical composition or mineralogical structure. The later lavas of Beinn Shiant and the Scùr of Eigg present still fewer points of difference from those of active volcanoes; and it would perhaps be more correct to speak of them as "trachytes" than as "porphyrites."

* The frequency with which crystals, often more or less worn and fractured, of various volcanic minerals, such as augite, biotite, the felspars, &c., are thrown out from the vents of volcanoes has been noticed by Mr. Scrope. Such crystals are found alike in the recent ejections of Stromboli, and imbedded in the tuffs connected with extinct volcanoes at Vulcano, Albano, Bracciano, Rocca Monfina, and some of the puys of Auvergne.

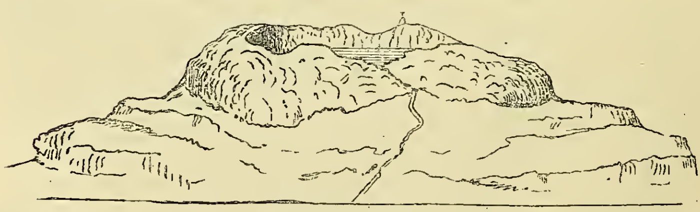
Seat, the volcanic origin of which has been so admirably illustrated by Charles Maclaren, Edward Forbes, and Archibald Geikie, the similarity of the phenomena presented by Beinn Shiant will be sufficiently striking; nor will he fail to recognize that in either case we have a much-denuded and ruined volcanic cone submitted to our study. The volcano of Beinn Shiant, however, was of far larger dimensions than that of which the ruins constitute Arthur's Seat.

Although the lava streams of Beinn Shiant are now, by denudation, reduced to more or less isolated fragments, yet such is their distinctive character that I believe there will be little difficulty, when the country is accurately mapped, in restoring the main features of this volcanic cone and of the lava streams which issued from it. Of the posteriority in date of this volcanic pile to both the felspathic and basaltic lavas of the great central volcanoes, we have the clearest evidence; for not only do its products overlie the sheets forming the great plateaux, but the fragments of the latter are included in great numbers in the agglomerates which compose it. Further, it is clear that these earlier lavas had undergone a vast amount of denudation before the outflow of those from Beinn Shiant; for the latter overlap the older basalts, and in places, where these have been wholly removed by erosion, rest directly upon the bared surfaces of Lower Silurian gneiss.

If in the case of Beinn Shiant we are unable to trace the igneous masses of this volcanic cone penetrating the older lavas and gneiss, this is solely due, as in the case of recent volcanoes, to the covering of ejected materials wholly concealing the relations of the rocks which lie below them. Fortunately, however, many examples of analogous later eruptions which have taken place within this district occur, wherein, as a result of the removal by denudation of the materials of the volcanic pile, the relations between the older lavas and the newer intrusive masses are very clearly exhibited. One of the most interesting of these we shall now proceed to describe.

At a distance of three miles to the south-west of the village of Tobermory in the island of Mull there rises, in the midst of the great plateau of basaltic lavas, a hill presenting somewhat striking features, known as Sarsta Beinn (see woodcut, fig. 4). Its height

Fig. 4.—*View of Sarsta Beinn from Stot Hill.*



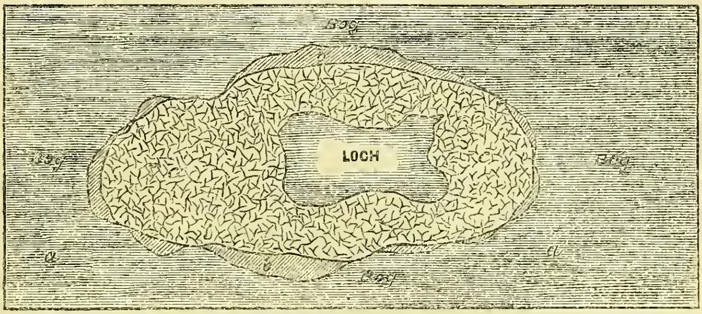
above the sea-level is apparently about 800 or 900 feet; but the peculiarity of the mode of weathering of the rock masses which compose it, as compared with the surrounding tabular basalts,

makes it a rather conspicuous object. Its summit is occupied by a small loch, or mountain-tarn, which is said to be of great depth.

When we examine this rocky mass standing up so abruptly in the midst of the basaltic plateau, we find it to be composed of a dolerite of the coarsest grain, passing in its lower portions into gabbro. The rugged, rusty-brown surfaces of these rocks, which resist denudation and the growth of vegetation, form a striking contrast with the grassy tabular masses of the basaltic lavas in the midst of which they rise.

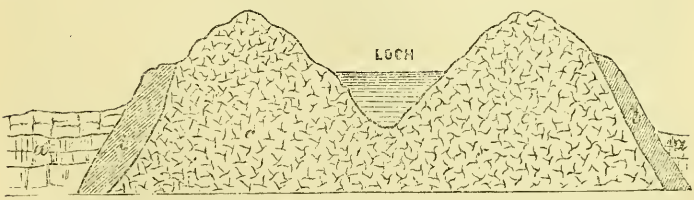
The identity in character between this rock mass and others of eruptive origin which we have before described is sufficiently obvious. That it was actually upheaved through the older basaltic lava sheets, we have the clearest and most unmistakable evidence. As shown in the plan and section (woodcuts, figs. 5 and 6), the contact between

Fig. 5.—*Plan of the Hill of Sarsta Beinn.*



a. Ordinary basalts covered by boggy ground.
b. Basalts altered by contact with the intrusive mass.
c. Great mass of coarse dolerite graduating into gabbro.

Fig. 6.—*Section of Sarsta Beinn.*



a. Basalts of the great plateaux.
b. Basalts altered by contact with the intrusive mass *c*.
c. Intrusive mass, composed of dolerite in places graduating into gabbro.

these highly crystalline rocks and the basalts in the midst of which they lie is marked by a belt of metamorphosed rock. The basalts near their junction with the intrusive dolerites and gabbro have acquired a harder texture, a splintery fracture, and a peculiar platy mode of weathering, often in concentrically curved planes. In con-

sequence of their greater hardness, an almost entire belt of the altered and indurated basalts is found surrounding the crystalline mass on all sides. From the central mass a number of dykes and veins can be traced intersecting the surrounding older lavas.

That, subsequently to the eruption of the great sheets of basaltic lavas, a mass of basic igneous rock was upheaved in their midst at Sarsta Beinn is evident. And that this eruptive mass was surmounted by a volcanic cone from which probably lava streams flowed, no one who has studied the example of Beinn Shiant will, I think, be disposed to doubt. Indeed fragments of these lava-streams may still remain, though now forming undistinguishable portions of the great basaltic plateau. When we remember the observation of Mr. Darwin, that both in the Cape-Verde Islands and the Galapagos archipelago he found it impossible to trace the boundaries of recently erupted lava streams, " except by the size of the bushes growing upon them, or by the comparative glossiness of their surfaces, characters which a short lapse of time would be sufficient to obscure," it will not be surprising that we are not, as a rule, able to trace the separate lava streams of the Hebrides. The fact that in the case of the lavas of Beinn Shiant we are able so to do, is due solely to the fact that in them a great capacity for resisting degrading influences is combined with remarkably distinctive petrological characters.

I have described in some detail these two examples of Beinn Shiant and Sarsta Beinn on account of their great size and typical character; but there is the clearest evidence that at a very great number of points the basalts of the great plateau were broken through by similar eruptive masses, sometimes, as in the case of Sarsta Beinn, composed of basic rocks, at others, as in Beinn Shiant, of more felspathic materials, and in others, again, of both these varieties. Few of these later eruptions appear to have been on the same grand scale as those which we have selected as types; and many of the intruded rock masses, which now alone remain to indicate their points of origin, are of quite insignificant proportions. Thus in the little island of Eigg two such masses were detected by Professor Geikie, and I have found a third of similar character; in the other islands also such masses are found scattered in all directions. Until, however, the whole district has been mapped in the most careful detail, it will be impossible to give a distinct view of the distribution of these latest points of eruption in the district, and to show their exact relations to the great volcanoes. Even after such survey, indeed, many of the smaller intrusive masses may escape the observation of the geologist through being concealed by peat-mosses or the vegetable covering.

Having pointed out that, even in the great mass of Beinn Shiant, the preservation of the ruins of the volcanic cone are due to very remarkable and exceptional circumstances, it will be almost unnecessary to add that the small cones which doubtless once surmounted most, if not all, of these eruptive masses, have in almost every instance been wholly swept away by denudation, and that the lavas which flowed from them have also disappeared or are now undistinguishable.

In the case of the celebrated Scùr of Eigg, however, I believe that we have a fragment of a lava stream which proceeded from one of these "puys," every other trace of which, however, has been removed. The character and relations of this interesting mass of rock have been very clearly illustrated by Prof. Geikie; and I would only suggest with regard to it that the characters of the buried conglomerate are suggestive of a mountain-ravine subject to the passage of violent floods rather than of an ordinary river-channel. It seems to me probable that this ravine was situated on the flanks of the great volcano of Rum*, then an extinct and rapidly disintegrating pile; that after the accumulation by the flooded stream of fragments of all sizes of lava and sandstone (all of which would be naturally derived from the ruins of that volcano) and the intermingling with these of uprooted trees (the *Pinites eggensis*) which grew upon its slopes, the whole was buried and sealed up in consequence of several lava streams, issuing from an (at that time) eruptive "puy," finding their way into and filling up the ravine. The course of the subsequent changes was similar to those long ago shown by Mr. Scrope to have taken place in so many instances in Auvergne; and, like these latter, they have raised up a striking monument to the power and duration of those forces which, almost unnoticed by us, sculpture the earth's surface. The history of the events connected with the formation of the Scùr of Eigg has been very clearly described and its lessons eloquently enforced by Prof. Geikie.

13. *Subterranean Phenomena of the Tertiary Volcanoes.*—In the preceding pages it has been my principal object to show that in the Hebrides we have evidence, mutilated and fragmentary it may be, but nevertheless most clear and unmistakable, of the occurrence of a series of phenomena which, alike in their character and their sequence, are identical with those exhibited by existing volcanoes. But interesting as these conclusions undoubtedly are, they are not perhaps the most important of the fruits of a geological study of the beautiful dissected volcanoes of the Highlands. Still more suggestive, from the circumstance that they enable us to correlate the familiar subaerial actions of volcanoes with others often regarded as wholly distinct in character and origin, are the phenomena presented to us when we study the connexions between the intrusive masses constituting the centres of these ancient volcanic piles, and the older stratified rocks through which they rise. To this most interesting subject I now proceed to direct attention.

The manner in which the surrounding strata are seen to be upheaved, contorted, and metamorphosed by the great eruptive crystalline masses, whether of acid or basic composition, has been already pointed out in a number of different localities. But in the case of the island of Skye, it was first shown by Dr. Macculloch, and after-

* As an example of a "puy" in Auvergne, similarly situated to that which appears to have given rise to the lavas forming the Scùr of Eigg, I may point to the Puy de Tartaret, which, rising in the Valley of Chambon, one of the great ravines cut on the flanks of Mont Dore, has poured forth a lava stream which has occupied all the lower parts of that great watercourse.

wards more clearly illustrated by Prof. Geikie, that besides the great central eruptive masses of granite there are other portions of the same rock, usually of a finer-grained character and passing into many varieties of felsite, the relations of which to the Primary and Secondary strata among which they lie is of a totally different kind. Instead of violently breaking through and disturbing them, these intrusive masses appear to form hills simply overlying the stratified rocks, but occasionally sending off veins into them and entangling portions of them in their mass; and in place of effecting a metamorphism in the sedimentary rocks extending for a great distance around, they produce only a comparatively small and local action upon them. These features, it must be confessed, seem at first sight sufficiently anomalous; and some authors have even gone so far as to describe these granites as having been poured out upon the existing surface "like ordinary trap rocks."

A careful study and comparison of all the phenomena presented by masses of this kind, numerous examples of which occur in connexion with the different volcanoes we have been describing, affords us a very simple explanation of the supposed anomalies. These masses of fine-grained granite passing into felsite are really portions proceeding from the great central masses and intruded between stratified rocks. In Skye, and also in some other cases, the overlying strata have been removed by denudation; and the intrusive rocks, which have by their hardness resisted denuding influences, now appear uncovered, and as if actually deposited upon the strata below. That the explanation now given of this phenomenon is the true one, I have been able to verify by the comparison of a very great number of cases, in which every stage of the series of operations here described as terminating in the production of the anomalous features in question, can be clearly traced. Admirable examples showing that these masses of granite and felsite were actually intruded among the stratified rocks, are seen in Raasay, Ardnamurchan, and Mull; I may especially cite the cases of Stron Beg and Craignure, situated in the two last-mentioned of these districts respectively, as illustrating the features and relations of such masses in a peculiarly interesting manner. A mass of this kind, probably originally connected with the volcano of Rum, occurs at the northern part of the island of Eigg; Professor Geikie notices the resemblance of the rock of which it is composed to the "quartziferous porphyries" of Skye and Raasay, and he justly states that the mass "appears to have risen approximately along the bedding of the Oolitic strata, and thus to form of itself a large rude bed"*.

In the very different modes of their subterranean disposition, the igneous rocks of acid and basic composition respectively present a remarkable parallel to the behaviour of the two classes of lavas to which they give rise. While the acid igneous rocks, when intruded between strata, tend to form thick lenticular masses, which are generally confined to within moderate distances from the great centres of eruption, the basaltic rocks, on the other hand, under like con-

* Quart. Journ. Geol. Soc. vol. xxvii. (1871) p. 294.

ditions, spread in vast sheets, which insert themselves along a plane of weakness between two sets of beds, and often proceed to enormous distances from the centres of eruption.

Very wonderful and striking are the relations between the great intrusive sheets of dolerite and basalt, connected with the great centres of volcanic action, and the stratified rocks which they traverse. These relations are exhibited in a very beautiful manner along the magnificent range of cliffs that forms the eastern boundary of the peninsula of Trotternish in Skye, and also in Raasay, Applecross, and the south of Mull. So remarkable is the regularity with which many of these sheets of molten rock have flowed between the same two strata for great distances, that it is not surprising they were for a long period regarded as being lava streams contemporaneous in date with the sediments among which they lie. A close examination, however, shows that these sheets of igneous material alter alike the rocks lying above and below them, and that they are altogether destitute of the vesicular character leading to the production of amygdaloids, as well as other features always presented by true lava streams. When, too, their courses are followed over considerable distances, they are found, in places, either bifurcating into separate sheets which enclose masses of the stratified rocks, or entangling fragments of these in their midst, or cutting for a time across the beds, or sending off processes and veins, or terminating abruptly in wedge-shaped masses, or breaking suddenly through the superincumbent strata, and so reaching the surface.

The rocks of which the great intrusive felspathic masses are usually composed, include many different varieties of felsite, usually more or less quartziferous, and often beautifully porphyritic in structure; these, in many places, by the appearance of scattered crystals of hornblende in their mass pass into a fine-grained syenite-granite. The intrusive sheets of basic rock consist in almost all cases of dolerite, often containing much olivine, and passing on the one hand into fine-grained gabbro, and on the other into many varieties of basalt.

Besides these larger masses, the igneous intrusions of all ages give rise to the formation of dykes and veins in prodigious numbers. Those of felspathic composition appear to be for the most part confined to within comparatively moderate distances from the eruptive centres; those of basaltic composition, on the other hand, are found proceeding to extraordinary distances from them. Prof. Geikie has even speculated, with much show of probability, on the existence of a connexion between the great basaltic dykes which traverse the whole of the rocks in the north of England and the great focus of igneous activity in the Hebrides. Basaltic dykes with such a connexion certainly traverse all the rocks in the west of Scotland in prodigious numbers; and the manner in which they sometimes, through greater relative capacity for resisting denuding forces, stand up like immense walls, and at others, by their more rapid decay, originate vast chasms, are facts which must have been observed by all who have travelled in the western Highlands. In the immediate neighbourhoods of the

great volcanoes their almost infinite numbers, the complexities of their intricate interlacings, and the manner in which those of later date cut across and often laterally displace portions of the earlier ones, give rise to a series of phenomena of the most instructive and interesting character. As a general rule, the larger the dyke the more coarsely crystalline is the mass of rock which composes it; and in many cases the middle of the dyke is composed of a coarser-grained rock than the sides.

Frequent allusion has already been made to the metamorphism produced in the Primary and Secondary strata, and also in pre-existing rocks, by the passage through them of masses of igneous rock. Careful examination will serve to detect such alteration at the surfaces of contact of almost every igneous mass; but in the *degree* of this action there is the greatest diversity in different cases. Sometimes it consists of a scarcely perceptible induration extending for a distance of a few lines only from the surfaces of the igneous mass, and unattended by any change in chemical characters; but in other cases the soft sediments of the Lias, Oolite and Cretaceous formations have had every trace of their abundant fossil contents wholly obliterated, and their masses converted into rocks undistinguishable in appearance and characters from the most highly metamorphic Primary rocks, with which, indeed, they have in some cases been confounded.

A careful study of these phenomena of local metamorphism enables us to enunciate the general law which governs its action to be as follows:—The degree of metamorphism and the distance to which its action extends from the intrusive mass is usually proportioned to the mass of the latter. Thus, the maximum of change is seen in the vicinity of the great eruptive mountain masses, and the minimum near the smaller intrusive veins and dykes; while around the various intrusive sheets and bosses every intermediate degree of alteration is exhibited. Even among dykes we can often observe that the amount of induration in the strata which they traverse, and the distance to which this extends from their surfaces, are directly proportioned to their width. There are, it is true, occasional apparent exceptions to this rule; but these are in most cases capable of easy explanation. Thus masses of rock traversed by a complete plexus of veins and dykes, such as are seen at some points in Ardnamurchan, undergo a very great amount of change, their fossils being almost wholly obliterated and very decided chemical changes induced in their mass, these changes being evidently the result of the *cumulative* action of the numerous small intrusions. The establishment of this law of metamorphic action serves to confirm what, indeed, is sufficiently obvious, that the metamorphism in surrounding rocks results from the passage of heat from the intrusive masses of molten matter as these gradually pass into the solid condition.

I can scarcely conceive of any series of phenomena more striking in character, and certainly of none more interesting and suggestive to a geologist, than those presented by the wonderful complexities produced by the mutual interferences of different eruptive rock-masses,

varying in dimensions from great mountain-groups down to the minutest veins and strings, exhibiting innumerable distinctions of mineralogical constitution, and belonging to three successive geological periods. Nor is it easy to imagine a more striking series of mechanical and chemical changes than those which in the surrounding strata have attended the eruption of these masses, resulting in the most extraordinary contortions and the extremest metamorphism.

Such features are admirably exhibited alike in the district of Strath in Skye, on the southern coast of Mull, and at various points around Rum, but in none in so striking a manner as in the peninsula of Ardnamurchan. Here the scalpel of denudation has revealed the intricate and curious relations of the several varieties of igneous rocks with one another and with the Primary and Secondary strata. To represent these, however imperfectly, would require a series of maps and sections on the very grandest scale; in many cases, indeed, adequate conceptions of the relations of such very intricate rock structures could only be conveyed by means of models. It is, however, to the rocks themselves that the student must be referred; and he will find in them illustrations of the characters and action of igneous intrusions which will amply repay him for the time and labour expended in their investigation *.

14. *Ages of the several Volcanic Outbursts already described.*—That the events of which we have been discussing the evidence, stupendous as they are in scale and complicated as they are in succession, all took place subsequently to the Mesozoic epoch, we have the most ample proof:—

First, in the fact of the entire absence of *contemporary* volcanic deposits among the Secondary strata. I have already alluded to the earlier misapprehensions which prevailed upon this subject, and on the manner in which these were removed by the observations of Prof. Geikie in 1865.

Secondly, in the circumstance that the volcanic masses are thrust through and among the representatives of the whole series of Secondary strata, up to and including the Upper Chalk; and that the volcanic products unconformably overlie and include numerous fragments of the whole of the Secondary rocks—these fragments having acquired their present positions either through being ejected from volcanic vents (as in the case of the breccias of Mull, Rum, &c.), or by the agency of ordinary denuding agencies opera-

* Below Mingary Castle, near Kilchoan in Ardnamurchan, a section may be observed which is interesting as throwing light on the probable mode of formation of the celebrated Puy Chopine in Auvergne, the peculiar and apparently, at first sight, anomalous characters of which have been frequently remarked upon (see Scrope's 'Geology and Extinct Volcanos of Central France,' pp. 72–76). At Mingary a mass of quartziferous porphyry has been forced between beds of Lower Lias shale, while a later-formed sheet of basalt has evidently taken advantage of the plane of weakness, constituted by their junction, to force itself between them. In the Puy Chopine a mass of the older rocks (in this case composed of granite) has been forced upwards by an extrusion of domite, while a sheet of basalt has similarly inserted itself along their line of junction.

ting in the intervals between the several outflows of lava (as in the chalk- and flint-detritus of Ardtun and Carsaig).

That, on the other hand, this remarkable series of events, even the latest of them, took place at a period very remote from the present, is proved by the enormous amount of denudation which the volcanic products have undergone.

I know of no more striking evidence of the vast duration of geological periods, than that which is afforded to us in the Hebrides, when we contrast the wonderful freshness of the contours, polished surfaces, and striæ produced during the Glacial period, with the everywhere abundant proofs of enormous denudation suffered by rocks of undoubted Tertiary age, many of these, moreover, being very conspicuous for their intense hardness and great capability of resisting weathering influences. How almost infinitesimal on such a comparison appears the time which has elapsed since the Glacial epoch, to the duration of the great Tertiary periods!

The facts adduced in the present paper show that there were three well-marked periods of igneous activity in the district, which were characterized as follows:—

First Period. The outburst in the midst of a terrestrial surface, composed of various Palæozoic and Secondary rocks, of ashes, scoriæ, and fragments of the rocks in which the vents were opened, alternating with the outflow of streams of highly felspathic lava. With these subaerial phenomena was connected the ascent of molten masses, in a manner to a great extent peculiar to rocks of acid composition, which, injecting the fissures of the surrounding and superposed rocks, consolidated into felsitic rocks in their outer portions, but in their deeper and more central portions, under different conditions of slow cooling and great pressure, assumed well-marked granitic characters.

Second Period. The extrusion from the same volcanic foci of masses of basic igneous materials, which on reaching the surface spread, after the usual manner of lavas of this class, into streams which, following one another at intervals, sometimes of long duration, gradually built up those enormous plateaux of basalt rock of which only mere fragments have escaped denudation. The same cruptions of basic rocks evidently gave rise to the formation of the mountain-masses of gabbro and the intrusion between and among the surrounding strata of innumerable and widely-spread sheets and dykes of dolerite and basalt.

Third Period. The appearance in a sporadic manner, in the neighbourhood of the grand old extinct volcanoes, of numerous minor outbursts of lava (felspathic, basaltic, or intermediate in composition), which, with the accompanying fragmentary ejections, gave rise to the formation of a series of volcanic cones, small, indeed, as compared with the vast mountain masses formed during the two preceding periods of eruption, but of which some at least were of no mean dimensions. The greater number of these would, to some extent, compensate for their inferior dimensions.

But from the facts which I have adduced in this paper it is also evident that periods of enormous duration must have separated these

three epochs of intense volcanic activity. This is evidenced by the unconformable relations which the rock-masses produced during the three periods of eruption bear to one another.

The proofs of extensive denudation having taken place in the interval between the outflow of the great masses of felspathic and basaltic lavas appear to be of a very decisive character.

(1) The basaltic lavas and their accompanying piles of scoriæ, rest *directly* in many cases, as is so well seen in both Rum and Mull, not on the lavas and ashes which must have constituted the outer portions of the earlier volcanoes, but on the intrusive felsites and granites which could only have formed their interior and deeply seated portions.

(2) The felspathic lavas, &c., are seen in Mull to have undergone considerable movements and to have suffered largely from denudation, before they were buried under the overwhelming products of the period of basaltic eruptions.

(3) It appears also that the basaltic streams frequently lie in hollows eroded in the preexisting felstones. This fact is not so easily made out as those before noticed; but I believe there are distinct proofs of it in Ardnamurchan.

The evidences of erosion on a very extensive scale having taken place between the period of the eruptions of basic rocks and that of the formation of the "puys" are not so easily traced as those of the former inter-volcanic period, owing to the almost complete removal of the latest-formed volcanic deposits of the district by denudation. But in the case of the Scùr of Eigg, as so clearly explained by Prof. Geikie, and in that of Beinn Shiant, which has been described in this paper, the proofs of unconformity between the lavas of the two series are sufficiently distinct and striking.

Lastly, of the enormous changes which have taken place since the period of the formation of the "puys," we have the clearest proofs in the total removal, with rare exceptions, of the volcanic piles which doubtless once surmounted those igneous protrusions, which now alone mark the sites of the latest series of eruptions in the district.

In the almost total absence of palæontological evidence, it cannot, of course, be absolutely demonstrated that the three series of volcanic outbursts which we have described were in the case of the different centres strictly synchronous; but the remarkable uniformity of characters, in the succession of products in all the different cases, leads to the very strongest presumptions in favour of a connexion having existed between these different foci, and of the contemporaneity between the several analogous phenomena manifested at each of them.

Our means of correlating these three epochs of volanic activity during the Tertiary period, with the divisions of the same era founded on the relations which its successive faunas bear to one another and to the existing creation, must be confessed to be small; and hence the results attainable by us on this subject are to a certain extent indecisive; nevertheless it will be well in this place to bring together the whole mass of evidence as yet obtained which bears upon the question.

The beds intercalated with the earliest series, that of the fel-

spathic lavas, have, as yet, furnished no organic remains. They are evidently, as a mass, post-Cretaceous; but I have observed some phenomena, which will be described hereafter, apparently pointing to the conclusion that volcanic activity must have commenced in the district before the Cretaceous period had altogether closed. May we not, therefore, bearing in mind these facts and also the strong proofs already detailed of unconformable relations between these felspathic lavas and the Miocene basalts, venture to refer the former, at least provisionally, to the great Eocene period?

The proofs of the Miocene age of the basalts constituting the great plateaux, both in the Hebrides and in Antrim, are as follows:—

At Ardtun in Mull, low down in the series, the following species of plants have been obtained from the pond-like hollows buried under streams of mud and lavas as before described.

Sequoia Langsdorffii, *Ad. Brongn.* (Taxites Campbellii, *Forbes.*)
Rhamnites (?) multinervatus, *Forbes.*
—— major, *Forbes.*
Rhamnites lanceolatus, *Forbes.*
Equisetum Campbellii, *Forbes.*
Filicites (?) hebridicus, *Forbes.*
Alnites (?) McQuarrii, *Forbes.*
Corylus grosse-dentata, *Heer.*

In the plant-beds intercalated in a series of lacustrine deposits at Ballypalidy, Co. Antrim, the following have been found:—

Sequoia Du Noyeri, *Baily.*
Pinus (?) Plutonis, *Baily.*
Cupressites MacHenryi, *Baily.*
Eucalyptus oceanica, *Unger.*
Daphnogene Kanii, *Heer.*

with fragments referred, somewhat doubtfully, to the genera *Platanus?*, *Fagus*, *Podocarpus*, *Andromeda*, *Quercus*, *Rhamnus*, *Hakea*, *Celastrus*, and *Graminites*. Also the elytra of two species of beetles.

In "ash-beds" between the basalts near Shane's Castle, Lough Neagh, Co. Antrim, the following were obtained:—

Platanus aceroides, *Göpp.*
Sequoia Langsdorfii, *Ad. Brongn.*

with fragments referred to the genera *Juglans*, *Fagus*, *Laurus*, &c.*

Both Prof. Edward Forbes and Prof. Heer concur in the opinion that these floras indicate that the beds in which they occur were deposited during the Miocene period.

Concerning the age of the last of the three periods of eruption, that of the "puys," the evidence from organic remains is much more scanty. It consists only of the fossil wood (known as *Pinites eggensis*, With.) found under the lava stream of the Scùr of Eigg, upon which, of course, no conclusion can be founded. Considering, however, the proofs already adduced, from their unconformable relations, of the separation of the deposits of this period alike from those of the Miocene and the recent epochs, we can scarcely hesitate to regard them as belonging, at least approximately, to the Pliocene†.

* *Vide* Forbes, Quart. Journ. Geol. Soc. vol. vii. (1853), p. 103; W. H. Baily, *ibid.* vol. xxv. (1869), p. 357; and Tate and Holden, *ibid.* vol. xxvi. (1870), pp. 162–63.

† In venturing thus to compare the three periods of volcanic activity in the north-western parts of the British Islands with those divisions of the Tertiary epoch which Sir Charles Lyell has founded upon a comparison of the molluscan

To those familiar only with the English representatives of the three great Tertiary periods, the Eocene sands, marls, and clays, of the London and Hampshire basins, the Miocene lignitiferous beds of Bovey Tracey, and the insignificant Pliocene deposits of the Crags, the evidences of such enormous physical changes, as we have shown must have taken place in the north-western portion of these islands during the same periods, will indeed appear startling. But to remove any feelings of difficulty or doubt which may have their source in such comparisons, it is only necessary to refer to the well-ascertained facts of the geology of the Alps, where events on even a grander scale than those which we have described, can be shown to have taken place during the same periods.

15. *Connexion between the Tertiary Volcanoes of the Hebrides and those of other districts.*—It would be foreign to the objects of the present memoir to enter upon a discussion of this most interesting question. I shall therefore only state that, while we have the clearest proofs of the contemporaneity of the basalts of Antrim with those of the Inner Hebrides, we have also strong grounds for regarding the granites of Arran and the Mourne Mountains as having been erupted during the same period with those of Skye, Mull, Rum, &c.* Thus we are led to the conclusion that along a line stretching at least 400 miles from north to south, in the north-western part of the British archipelago, there rose, during a great portion of the Tertiary period, a chain of volcanoes in a state of violent but intermittent eruption. But continuing this line to the northwards, we find the proofs of volcanic action during part of the Tertiary period (and in some cases, at least, this action has not yet become extinct) in the Faroe Islands, Iceland, Jan Meyen, and Greenland. And southward the same line of volcanic vents is continued in Central France, the Iberian peninsula, the Azores, Madeira, the Canaries, Cape-Verde Islands, Ascension, St. Helena, and Tristan d'Acunha.

When we remember the proofs of the existence of widely spread terrestrial conditions during the Miocene epoch, and the interesting facts concerning the distribution of existing terrestrial species, made known to us by the labours of Edward Forbes, Unger, Heer, and others, we may well be prepared to regard these isolated masses of volcanic rocks, as has been suggested by Professor Nordenskiöld, as portions of a great ridge now for the most part submerged beneath the sea-level and constituting a boundary to the great eastern continent, similar to that which the Andes, Cordilleras, and Rocky Moun-

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faunas of certain deposits with those of recent seas, I am actuated by a feeling of the necessity of such a comparison to a due appreciation of the subject, rather than by a belief in the possibility of establishing any thing like actual *contemporaneity* between divisions based respectively on purely palæontological and physical evidence, both of which series of divisions, moreover, are incapable of very exact definition and limitation.

* My friend, Mr. Thomas Davies, has called my attention to the fact that the granite of Lundy Island offers peculiarities of structure strikingly similar to those presented by the granites of the Mourne Mountains, Arran, and the Northern Hebrides. It is possible, therefore, that in Lundy Island we have relics of another of the centres of volcanic action during the Tertiary period.

tains form to the western. The recent soundings of H.M.S. 'Challenger' have not only confirmed these conclusions, but have shown that the elevation of this old Andes of the eastern continent was not inferior to that of its existing homologue in the western, and that some of the peaks rose to the height of at least 25000 feet above the surrounding plains.

16. *General Conclusions from the relations between the Volcanic and Plutonic rocks of the Tertiary period.*—The study of the rocks of the Inner Hebrides has clearly demonstrated a fact which had been already strongly suspected by Dr. Macculloch, Prof. Geikie, and other geologists, that the granitic rocks of that area had a close connexion and were of contemporaneous age with the old lava streams so extensively developed in their neighbourhood.

We have shown how, by the more or less complete removal of its upper portions and the consequent exposure of its deeply seated rocks through denudation, a volcano may present many different aspects—from examples such as that of Mull, in which the relations of the various volcanic products can still be easily traced, to others, like that of Skye, in which these relations are by no means so clear at first sight. It will be easy to conceive a still further stage of ruin in a volcano in which, all the surrounding lavas and other erupted materials being removed, we should have left only the central core of granite or gabbro (the latter perhaps altered into various serpentinous rocks) rising in the midst of a series of stratified rocks; and in such cases there would be nothing to connect such eruptive masses with the ordinary subaerial phenomena of volcanic activity.

When we reflect on the striking similarity of the products of this series of Tertiary volcanoes, we can scarcely doubt of their connexion, or of their materials having been derived from a common reservoir. It is, under these circumstances, easy to imagine that, by the total removal of the superincumbent rocks, the consolidated contents of this old reservoir may be exposed. In such cases we might reasonably expect to find at the surface a tract of granite of wide extent, like that of Leinster.

Fortunately the same district which we are now studying affords us, in a series of igneous rocks of older date than those already described, a number of beautiful illustrations and convincing proofs of the truth of these views concerning the relations between the Volcanic and the Plutonic rocks. These we now proceed to describe.

III. *The Newer Palæozoic Volcanoes.*

That there is evidence in the Highlands of Scotland of a great period of volcanic activity which *preceded* the deposition of the Secondary strata of the district has been already pointed out. I shall proceed to show that the eruptions of this earlier period were on a scale of at least equal magnitude with those of the Tertiary epoch just described, that like these latter they gave rise to the formation of vast plateaux composed of lava streams surrounding on all sides great volcanic mountains, and that under the action of denuding

forces these plateaux have been broken up into more or less isolated fragments, while the central volcanic cones have been so worn away as to have lost many of their distinctive features. From the facts to be adduced it will clearly appear that, prior to the Mesozoic epoch, the greater part of the southern and central districts of Scotland, both north and south of the Grampians, was covered to the depth of thousands of feet by the products of igneous activity and the strata enclosed between them. But, as might be anticipated from their far greater antiquity, the lava plateaux of this earlier period are in a more fragmentary condition, and its volcanic cones in a far more ruined state than those of the Tertiary period. Aided, however, by the analogies of the latter, I hope to be able to demonstrate what were the principal characters of this earlier volcanic period, to trace the history of the succession of events which took place during its continuance; but more especially, as bearing upon the objects of the present inquiry, my endeavours will be directed to the reconstruction of those ancient physical features which resulted from these volcanic outbursts, and which to so great an extent determined the conditions under which the Mesozoic strata were deposited.

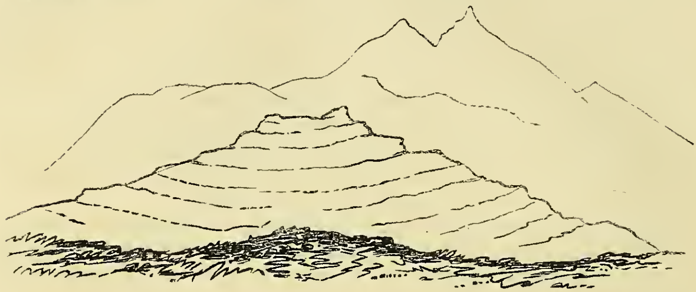
1. *Lavas of Lorn and the adjacent islands.*—In the same district of the Western Highlands with the Tertiary lavas already described, and in close proximity to them, we find another series of volcanic rocks belonging to a very different geological period. They occupy a large portion of the district of Lorn, and are also extensively developed in the south-eastern part of Mull, in Kerrera, Seil, and the smaller islands in their vicinity. By Loch Etive this volcanic tract, which extends about 22 miles from north to south and 18 miles from east to west, is divided into two very unequal portions—the smaller and northern portion extending through Benediraloch towards Loch Creran, and the larger and southern portion to the neighbourhood of Loch Awe and Loch Melfort. An examination of the boundaries and relations of this volcanic tract shows that it must be regarded as a fragmentary patch of a series of deposits once widely spread, which has been preserved from denudation, like so many other masses of rock of various ages in the Highlands of Scotland, through being let down between great faults or within vast synclinal folds. This conclusion is fully borne out, as we shall hereafter see, by the existence of small and distant isolated patches (outliers) of the same formation.

Until very recently the "trap-rocks" of Lorn were confounded with those of Tertiary age which are developed in their immediate neighbourhood. Macculloch appears to have considered that the sandstones and conglomerates which occur at their base were part of the Secondary series of the Highlands, while Prof. Nicol suggested that they might represent the Trias. In the map of Scotland published in 1861 by Sir R. Murchison and Prof. Geikie the "traps" of Lorn are indicated as being of Old Red Sandstone age.

The general features of the district occupied by these rocks, and the scenery to which they give rise are those which usually characterize tracts of rocks of volcanic origin. These are well illustrated by the annexed outline sketch of the mountain which rises at the eastern end

of Glen Lonnan (woodcut, fig. 7). When compared with the great plateaux of the Tertiary lavas which have been already described, a number of points of difference, however, will be remarked. The wonderful regularity of the terraced features, so strikingly displayed by the basaltic plateaux of the Tertiary period, are to a certain

Fig. 7.—*Outline Sketch of a Mountain near Glen Lonnan, illustrating the Mode of Weathering of the Porphyrite and Felstone Lavas of Lorn.* (The granitic peaks of Beinn Cruachan are seen in the background.)



extent wanting in the piles of felspathic lavas which were poured out before the deposition of the Secondary rocks; the cause of this difference is of course to be sought in the usually greater fluidity and consequent even diffusion of the lavas of basic as compared with those of acid and intermediate composition.

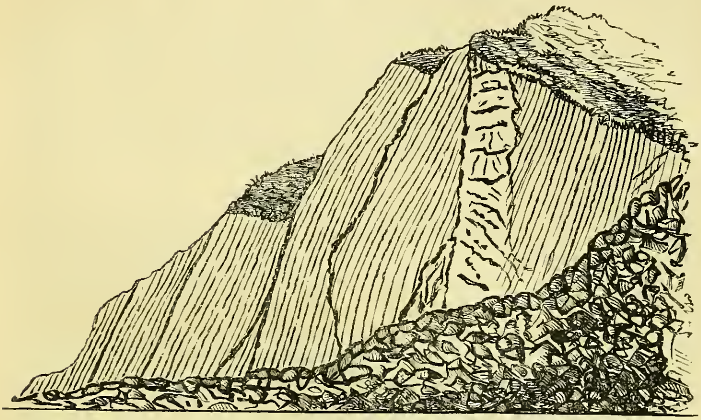
2. *Characters of the Volcanic Rocks of Lorn.*—As already intimated, the great mass of these lavas is of felspathic or acid composition, and includes innumerable varieties of the rocks which were formerly known by the names of felspar-porphyry, compact felspar, clinkstone, claystone, &c. For the most part they may be regarded either as varieties of the rocks included in this country under the name of "felstone," or of the extensive class called "porphyrites" upon the Continent—the former representing the quartz-trachytes, and the latter the ordinary trachytes of modern volcanoes.

The changes which have taken place in many of these rocks subsequently to their deposition have been such, as in many cases to mask their real origin as lava streams; in this respect, however, we find the greatest variations in the same mass of rock. A close examination of the structure and relations of these rocks will, in almost every instance, furnish many interesting points of evidence bearing upon their mode of origin.

The columnar structure is by no means so common among the felspathic lavas as among those of the basaltic class; nevertheless some interesting examples of it are afforded by the rocks of Lorn. The columnar forms assumed by the acid lavas present distinctive characteristics of their own, as compared with those of the basalts. In the former class of rocks the columns are usually of smaller diameter and

less regular form, while they often extend to much greater length than those of the latter class, unlike which again they are never divided into regular blocks by equidistant, curved, joint-planes. One of the best examples of the columnar structure among the old lavas

Fig. 8.—*Cliff-section, S.W. of Oban, exhibiting very fine Columnar Structure in the Porphyrite Lavas of Lorn.*



of Lorn is that exhibited in a cliff about two miles south-west of Oban, where the columns are of great length and beautifully curved (see woodcut, fig. 8); but more or less perfect examples of the same structure are exposed on the face of Beinn Lora and at other points.

Some of the volcanic rocks of Lorn present characters which, at first sight, appear not a little anomalous and puzzling; but this is a circumstance which, when we remember the metamorphic processes to which lavas, in common with all other rocks, are subject, need scarcely occasion surprise. Certain of the lavas appear after their emission to have weathered into the characteristic spheroidal and concentric forms, while others have evidently decomposed into a "wackose" condition; and in both cases the rocks which result from the re-induration of such masses, present very peculiar features, and may, in some instances, be mistaken for consolidated "trap-tuffs."

The separate lava-flows were often of enormous thickness. As a general rule the great body of each of these streams is made up of a compact, often highly porphyritic rock; but towards the upper and under surfaces of the mass, it usually assumes the amygdaloidal structure. The amygdaloidal cavities, which have evidently served as chemical laboratories in which very complex operations have been carried on, are frequently deprived of their contents by recent weathering operations; and the original structure of the rocks is thus to a great extent restored. Then is made clearly apparent the originally highly vesicular character of the upper and under portions of these ancient lava streams, the vesicles being often seen to be drawn out in the

direction of the flow, while the actual surfaces of the stream exhibit the most strikingly scoriaceous aspect. The same weathering process sometimes develops in these old lavas other original structures, which had become wholly obliterated by infiltration, crystallization, and other processes taking place in the mass of the rock; and these structures would have remained altogether unsuspected but for the action of this cause. Thus some highly crystalline and porphyritic rocks, when weathered, resume their earthy or compact texture; and in certain cases structures like the sphærulites of pearlstone, which had become wholly obscured in the mass, are again revealed. Similarly many rocks of very solid appearance are seen, when the infiltrated materials are removed by weathering, to have been originally aggregates of ashy, pumiceous, and scoriaceous fragments, among which "volcanic bombs" or their fragments may not unfrequently be detected*.

3. *Relations of the Volcanic Rocks of Lorn.*—In considering this question it is important at the outset to notice two striking facts with regard to the positions of the lavas and associated beds of Lorn. In the first place they always rest directly, but unconformably, upon the Lower Silurian gneissose and schistose rocks, and never exhibit any of the fossiliferous Secondary strata at their base; in this respect they present a striking difference in their relations from the Tertiary lavas of the adjoining districts. And, secondly, they are, like the older rocks upon which they repose, penetrated in every direction by numerous dykes of dolerite and basalt; these are precisely similar to the intrusive masses associated with the Tertiary volcanic rocks—of which series, indeed, we can scarcely hesitate to regard them as forming a part.

These later dykes of dolerite and basalt, which are sometimes of great width, and often present a prismatic or columnar structure, constitute a most interesting and striking feature in the district. In consequence of their usually greater relative hardness, they frequently stand up like gigantic walls amidst the rocks of slate and felstone which once enclosed them but have now been weathered away from their sides.

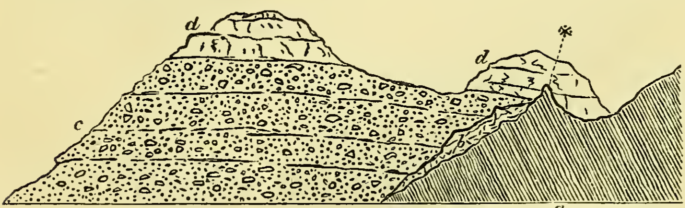
The remarkable series of volcanic rocks of Lorn is probably several thousand feet in thickness—though, its upper portions having been everywhere removed by denudation, its original limits in this respect are quite unknown to us. Its relations to the slate rocks and certain conglomerates, sandstones, and breccias appear, at first sight, to be

* That the geologist never meets with glassy lavas (obsidians, pitchstones &c.) among the older rocks will not occasion any surprise when we reflect upon the facility with which *artificial* glasses undergo devitrification. That glassy lavas were formed even in palæozoic times appears to be indicated by the fact recorded in the text that weathering sometimes reveals the characteristic *sphærulitic* structure in some of the lavas of Lorn. Many of the Newer Palæozoic "porphyrites" of Scotland are quite undistinguishable in appearance from some trachytes, such as those of Hungary. The white granular siliceous rocks into which the former are sometimes found altered, appear to be equally undistinguishable from the products of the decomposition of the latter (occasioned by the passage of acid vapours through them), and constituting the so-called "Alaunstein."

so anomalous as to have occasioned no little difficulty to the older geologists who sought to explain them ; indeed the slate rocks were found to occcur at such various levels among the series of lavas, conglomerates, and sandstones, and in such unexpected situations, as quite to baffle Macculloch and other observers who sought to illustrate their relations by horizontal sections*.

That in a district so disturbed as this has been shown to be, the strata in question should be found to be traversed by great faults will occasion no surprise ; and among rocks of such inconstant characters as these, it is, moreover, not easy to detect and follow the details of such dislocations, though their general effect may often be sufficiently obvious. Thus in the island of Kerrera a N.W. and S.E. fault, with a throw of not less than from 500 to 600 feet, is very conspicuous. It is not, however, to these dislocations, striking as their effects undoubtedly are, that the anomalous position of the rocks in question is mainly due, but rather to the fact that the volcanic and associated rocks were accumulated upon an old terrestrial surface of great irregularity, the hills and peaks of which stand up at very various levels amidst the great mass of overlying rocks. From the examination of the sections near Oban, in the island of Kerrera, and on the shores of Lochnell Bay, this relation of the several rocks becomes sufficiently clear. Sometimes, in favourable sections, peaks of the Lower Silurian slate rocks are actually seen standing up amid the overlying deposits, while in other cases hills composed of the former rock stand in such a manner amid surrounding masses composed of nearly horizontal beds of conglomerate, sandstone, and lava, that no doubt can remain that the former constituted, prior to the denudation which has sculptured the existing surface, the sides of valleys which were subsequently filled

Fig. 9.—*Section through the Highest Point of the Island of Kerrera, illustrating the Relations between the Slate Rocks and the overlying Volcanic Series of Lorn.*



a. Lower Silurian slates. *b.* Breccia composed of angular fragments of *a.* *c.* Conglomerates and sandstones. *d.* Porphyrite lava-streams. * Slates baked and altered by the enveloping lava.

with the deposits of the latter. Interesting examples of such slate hills again exposed by denudation are found at the "mythical Beregonium" (where the mass is crowned by a vitrified fort) and near the town of Oban. The accompanying section (woodcut, fig. 9)

* *Vide* Macculloch's 'Western Isles of Scotland,' vol. iii. pl. xvi. fig. 3, p. 14.

will serve to illustrate the peculiar relations of the several rocks in these cases.

The rocks on which the volcanic series of Lorn usually rests are black clay-slates, abounding in fine cubical crystals of pyrites and often traversed by numerous veins of quartz. This formation is perhaps the highest member preserved to us of that great series of Lower Silurian rocks which, bent into endless folds and greatly metamorphosed, occupies so large a portion of the Scottish Highlands. At Seil and Easdale it is extensively worked for roofing-slates; as yet, unfortunately, it has not yielded any fossils; but it exhibits in the island of Seil interbedded igneous rocks, apparently of *contemporaneous* character.

The only point at which the series of rocks so well displayed in Lorn is seen in juxtaposition with the Mesozoic sedimentary rocks and the Tertiary lavas is in the south-eastern part of Mull. Here, unfortunately, among the wonderfully disturbed and greatly metamorphosed rocks, which are exposed only in precipitous and altogether inaccessible cliffs, I have sought in vain for any simple section illustrating the relations of these three series of deposits. Nevertheless, after carefully tracing the positions of such masses as can be reached and studied, there appears to be no room for doubt that the various members of the Mesozoic series rest indifferently upon the denuded lavas of Lorn and the older rocks, and that they are themselves covered unconformably by the Tertiary volcanic rocks.

4. *Succession of Rocks in Lorn.*—The series of rocks which we have been describing has usually been represented as consisting of beds of conglomerate and sandstone at the base, overlain by a great mass of "trap" rocks. A careful examination of the district, however, proves that its structure is by no means so simple as this statement would imply. The outpouring of the great lava streams was, in part at least, contemporaneous with, as well as subsequent to, the deposition of the conglomerates and sandstones. This is proved by the alternation of the "trap" rocks with the conglomerates and sandstones, and by the fact that the materials of the latter are to a great extent derived from the former. Good examples of the alternations of the traps with the sandstones and conglomerates are to be seen near Dunolly.

At the base of the whole series of the Lorn rocks, and in immediate contact with the subjacent slates, is often found a breccia of very interesting character. It is wholly composed of perfectly angular fragments, sometimes of considerable size, of the slate and quartz rocks on which it rests; this breccia exhibits no trace of stratification or of its materials having been sorted or acted upon by water. It sometimes forms masses of considerable thickness, which appear to have been accumulated upon old terrestrial surfaces of the slate rocks by purely subaerial agencies.

The conglomerates of the Lorn series present very remarkable characters, which are familiar to all who have examined the picturesque cliffs on either side of the beautiful Bay of Oban. They are made up of blocks of very various sizes, occasionally angular but

usually subangular or well-rounded, of "trappean" materials mingled with others derived from the metamorphic rocks. These blocks are so firmly cemented together by a sandy matrix, derived from the same materials, that the great joints which traverse the rock in all directions, and give rise to the bold and fantastic forms which it assumes under denudation, frequently cleanly divide the separate pebbles of which the rock is made up, even when they are composed of the hardest known materials. These conglomerates, which attain to thicknesses of hundreds of feet, exhibit great variations in the size of their materials, sometimes passing into coarse sandstone, which usually occupies lenticular patches in their midst, and at others containing blocks of very large dimensions. In the remarkable naturally isolated pillar of this conglomerate near Dunolly Castle, which is known by the name of Clach-a-choin, there is a single block of felstone, 8 feet long, 6 feet broad, and 5 feet thick; and many similar blocks of almost equal dimensions are seen at other points.

The sandstones of the Lorn series vary from very coarse grits, almost wholly made up of felspathic materials, to fine micaceous sandstones, exactly resembling those so abundant in, but by no means peculiar to the Old Red Sandstone. These sandstones are usually of a grey colour, but sometimes brownish-red. They frequently exhibit much false-bedding, and sometimes contain fragments of rock of considerable size but of flat form, such as can easily be borne along by currents of water. In many places they include bands of pebbles of very various size, and thus graduate into the conglomerates.

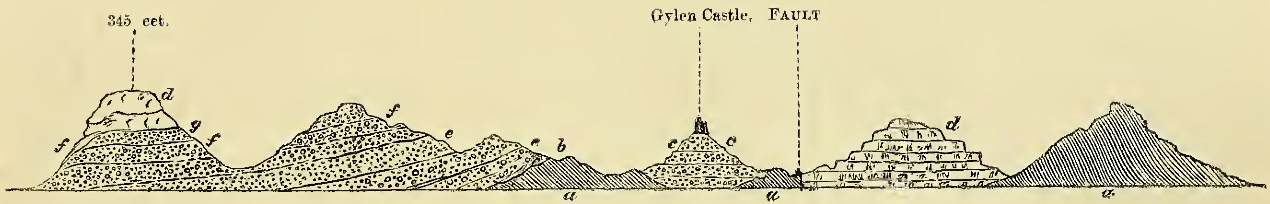
With the conglomerates, sandstones, and "traps" are interstratified a number of subordinate beds of peculiar character; of these some are composed of well-stratified materials of excessive fineness, which appear to occupy pond-like cavities in the midst of the other beds; and these seem to be made up of the fine volcanic dust so frequently ejected in great quantities from volcanic vents. In other cases we find well-stratified beds of small angular fragments of igneous material (lapilli &c.), constituting "tuffs" precisely similar to those of modern volcanoes.

As might be anticipated from the characters of these rocks, there is no appearance of a regular order of succession among them; but on the contrary the deposits are of the most local description. In order to illustrate their mode of occurrence I give a section taken along the south end of the island of Kerrera, where these strata are especially well exposed (woodcut, fig. 10, p. 284).

From the descriptions already given of the relations of the series of rocks in Lorn, it is clear that the lava streams must sometimes be found in contact with the slates, at other times with the conglomerates, and at others, again, with the sandstones. The appearance presented by each of these junctions I propose to describe in illustrative examples.

In the island of Kerrera we find a remarkably interesting example of the contact of one of the lava streams with the slate. Here a pinnacle of slate rock protruding above thick masses of sandstone and conglomerate, in the manner already described has been involved in

Fig. 10.—*Section along the South End of the Island of Kerrera, Lorn.*



a. Slate rocks (Lower Silurian), with quartz veins.
b. Breccias composed of angular fragments of Lower Silurian rocks.
c. Conglomerates, mainly composed of pebbles and blocks of Lower Silurian rocks.
d. Lavas of Lorn (felstones and porphyrites).
e. Thick beds of greenish-grey sandstone.
f. Coarse conglomerates, with many pebbles and blocks of the lavas of Lorn.
g. Very coarse grey sandstones.

a lava current. The dark-blue highly cleaved slate is changed to a soft grey rock, divided into angular fragments by numerous joints, while the brilliant crystals of iron-pyrites with which the slate is studded are converted into a black amorphous substance still filling the original cavities (see woodcut, fig. 9, p. 281).

Many examples of the contact of a lava stream with a bed of sandstone are exhibited in Lorn and the adjoining islands. The sandstone, while still exhibiting more or less clearly, under the lens, its original granular structure, has for some depth from its surface been converted into a substance of intense hardness, and the mixture of felspathic and siliceous materials of which it is composed has evidently undergone incipient fusion.

Where the lava has flowed over a bed of conglomerate, the pebbles of the latter have been frequently caught up and enveloped in the mass of vesicular and scoriaceous rock forming the base of the lava stream, in a manner which has often been described as taking place in the case of the products of recent volcanoes*.

In a road-cutting in the vicinity of Oban I found a very interesting illustration of the phenomena presented at the contact of some of the lava streams with the beds below. The section was as follows:—

(*a*) Compact dark-coloured felstone lava, which has apparently undergone considerable alteration; here and there a hollow vesicle occurs in the mass. A thickness of 15 or 20 feet of this rock is seen in the section.

(*b*) About nine inches or a foot from its base this mass of lava becomes highly vesicular or scoriaceous, the cavities being strikingly flattened and drawn out. Many burnt-looking fragments (lapilli) are caught up in this part of the lava stream.

(*c*) For a depth of about 2 feet below we have a confused mass of vesicular lava, rounded blocks of lava, pebbles of quartz, &c., all imbedded in a matrix of highly scoriaceous rock. The lower part of this mass passes in places into a sandy conglomerate; the ordinary coarse sand consisting of lava detritus constituting the matrix.

(*d*) Conglomerates, composed of pebbles of trap and of the Lower Silurian rocks, with some unmistakable volcanic bombs, and with a matrix of very coarse sand, 2 feet thick. In this bed are lenticular patches of a very fine-grained sedimentary material, probably stratified volcanic dust.

(*e*) Beds of well-stratified and finely laminated red sandstone, very similar in character to the typical rocks of the Old Red Sandstone.

The stream of lava of which (*a*) and (*b*) form the lower portion appears to be 40 or 50 feet in thickness, to be highly vesicular in its upper part, and to be covered directly by another lava stream. The appearance presented by (*b*) and (*c*) is exactly such as would be produced by a lava stream with a cindery crust which it rolls over as it flows along, in the manner so graphically described by Mr. Scrope, and passing over a mass of shallow-water deposits, the materials of which it entangles in its course.

The sandstones and conglomerates, which in places attain to a thickness of several hundreds of feet, appear to be wholly confined to the *lower* part of the volcanic series of Lorn. In its upper part

* In the island of Lipari there occur beautiful instances of lava streams of glassy character having entangled in their mass many fragments of the older rocks, that have evidently strewed the surfaces over which they flowed.

that series consists of stream after stream of lava piled one upon the other in almost endless succession ; and so far as I have observed, these include between them no stratified deposits. The mode of weathering peculiar to "trap" rocks, while it often exhibits large faces of the different lava currents, causes their junction to be usually buried beneath a talus of fallen fragments. Nevertheless we are able to observe at many points, as near Loch Feochan, Loch Nell, and Glen Lonnan, that between the old lava streams there occur masses of a peculiar rock, usually of a bright red colour. At first sight these red rocks present but little resemblance to "trap-tuffs," being often extremely hard and compact in texture, through the infilling of their pores with crystalline materials. Fresh fractured surfaces, however, show that the rock is made up of angular fragments of lava, &c. (*lapilli*), quite unstratified ; and here, again, weathering processes come to the aid of the geologist, and, by removing to some extent the crystallized materials from the interstices of the rock, reveal its true tufaceous structure. Occasionally too we find in the beds unmistakable fragments, and more rarely entire examples, of volcanic bombs ; but these it is seldom possible to extract entire, owing to the jointed structure which they have acquired since being imbedded in the rock wherein they lie.

5. *Conditions under which the Volcanic series of Lorn was deposited.*—The highly irregular surface of the old slate rocks, with its hollows filled by breccias composed of their angular fragments, points to the existence of an old land-surface. Upon this, as we have seen, the accumulation of lava sheets and great masses of conglomerate and sandstone appears to have gone on simultaneously for a very considerable period. The stratified rocks associated with the lower lava sheets of the Lorn series are of such an extremely local and irregular character, that they do not by any means necessarily imply a subsidence of the old land-surface beneath the sea-level. On the contrary, the accumulation of large blocks of the local rocks, with alternating seams of sand of various degrees of fineness, would seem rather to indicate the action of mountain-streams subject to violent floods. The causes so clearly described by Mr. Drew * as having given rise to the formation of the great fan-shaped masses of alluvium in India (the nature and disposition of the materials of which would seem to be strikingly similar to those of the beds we are describing) appear to me to be fully competent to the production of the peculiar deposits of Lorn.

It therefore appears that the remarkable series of rocks in Lorn was accumulated along the flanks of a range of lofty volcanoes, the heaping up of conglomerates by mountain-torrents and the outpouring of lava streams, under which these were buried and preserved, going on side by side †. During the formation of the upper

* Quart. Journ. Geol. Soc. vol. xxix. p. 441.

† Mr. Scrope has clearly described the important part which is played by violent floods (resulting either from the sudden melting of snows on volcanic cones during their eruptions, or from the condensation of the enormous quantities of vapour to which they give origin) in distributing and rearranging the materials thrown out from volcanic vents.

and larger part of the Lorn series the volcanic forces appear to have been almost the sole agency concerned in the accumulation of the rocks; for these consist of subaerial lavas alternating with unstratified tuffs.

6. *Age of the Volcanic series of Lorn.*—In the entire absence of palæontological evidence, this question must be admitted to be still to a certain extent an open one. In forming a judgment concerning it, however, we have the following facts to guide us:—

(1) The very marked unconformity between these rocks and the strata of Lower Silurian age on which they lie. The latter were evidently not only deposited, but bent into great contortions and folds, and brought to their present metamorphosed condition, before the period of the formation of the former.

(2) The fact that the Mesozoic strata appear to rest upon them, and, in some instances at least, quite unconformably.

(3) The resemblance which the lava streams, of which they are so largely composed, present in their petrological characters to others on the south of the Grampians, which sometimes alternate with strata containing fishes of Old-Red-Sandstone species.

With these points of evidence before us, we can scarcely hesitate to regard the volcanic and associated rocks of Lorn as belonging to some part of the Newer Palæozoic periods; but to hazard any closer approximation to their age would probably be unsafe.

7. *The Newer Palæozoic Lavas of the Lowlands of Scotland.*—South of the Grampian Mountains very large areas of Scotland are occupied by series of old lavas, which, so far as mineral characters go, present very striking resemblances to those of Lorn which we have been describing. These rocks have been more or less fully described by many authors, and the evidences of their volcanic origin and of the conditions under which they were accumulated very ably discussed by Maclaren and Prof. A. Geikie. Moreover the districts where they are developed are now being mapped by the Geological Survey, and the relations and characters of these old lavas are being very admirably illustrated by the maps, sections, and memoirs issued by that department. Under these circumstances it will only be necessary for the purpose of the present argument to refer briefly to the general characters presented by these interesting rocks.

Nearly the whole of the hill-ranges of Central Scotland, such as the Ochils, Sidlaws, Pentland and Braid Hills, Campsie Fells, Kilpatrick Hills &c., are composed of these volcanic rocks. The preservation and present positions of the masses of these rocks which still remain, appear to have been determined by the great N.E. and S.W. faults which traverse the country. The exact positions and effects of these lines of fracture are very admirably shown on the detailed maps of the Survey, so far as it has gone.

The lavas composing these great ranges of hills, which are in some cases over 2000 feet in height, consist for the most part of rocks of a more or less felspathic character, though not usually so highly siliceous as those of the earliest Tertiary period. Like those of Lorn they commonly display in a very marked manner the

porphyritic structure. Occasionally, however, streams of a more basic character, and approaching to basalts in composition, alternate with the felstone lavas. With regard to the nomenclature of these rocks great confusion and uncertainty still unfortunately prevails. By Jameson and his pupils they were distinguished as porphyries, clinkstones, compact felspars, claystones and basalts. In the earlier publications of the Geological Survey they are referred to as "felstones;" and in the later works published by that department an attempt has been made to assimilate their nomenclature to that adopted on the Continent by applying to them the terms porphyrite, melaphyre &c.

The lavas of Central Scotland, like those of Lorn, have, as a rule, undergone a far greater amount of change from chemical action than those of the Tertiary period. Consequently in many cases their mode of origin is by no means so obvious as in the case of these latter; and in some places not only have they undergone a very great amount of general alteration, but mineral veins have been formed in their mass.

Strikingly similar as the lavas of Lorn are to those of Central Scotland in their petrological characters, they nevertheless present in their relations one very marked point of contrast. While the lavas of the northern flanks of the Grampian Mountains are, with the exception of the conglomerates and sandstone near their base, only separated by thin bands of interstratified ash &c., the similar lavas of Central Scotland alternate with great masses of sedimentary rocks, conglomerates, sandstones, limestones, shales, and beds of stratified ash. While the rocks of the former appear to be the products of a series of subaerial volcanic eruptions, those of the latter are not less clearly seen to have been formed by the outburst from time to time of streams of lava, which flowed over the beds of seas or lakes in which the accumulation of stratified sediments was going on.

With regard to the age of the great lava sheets of the Scottish Lowlands we are fortunately supplied with the most satisfactory evidence. The associated contemporaneous sedimentary rocks occasionally contain fossils; and thus we are able to define the age of different parts of them as Lower, Middle, and Upper Old Red Sandstone and the lower part of the Carboniferous (Calciferous Sandstone). Some difficulties still remain, it is true, with regard to the ages of some of the isolated portions of what once constituted great plateaux of volcanic rocks covering a very large portion of Scotland. This is due to the fact that many of the fossils, especially those of the Old Red Sandstone, are very local in their mode of occurrence; but that strata belonging to all the periods enumerated are found interbedded with these ancient lavas is indisputable. Towards the latter part of the period indicated (namely, during the deposition of the Calciferous Sandstone) the lavas show a general tendency to a more basic character than those of earlier periods, and thus form a transition to the basaltic eruptions of a sporadic character by which the great series of volcanic phenomena extending

through the whole of the Newer Palæozoic periods was brought to a close.

8. *The Eruptive Masses of the Grampian Mountains.*—From Peterhead, on the north-east, to the Ross of Mull, on the south-west, there occur, along the whole course of the Grampian Mountains, as is well known to all geologists, a series of masses of crystalline and igneous rocks which have evidently been protruded through the contorted and metamorphosed strata of the Lower Silurian. At an early period in the history of geology these rocks excited much attention, from their bearing upon the controversies then raging between the supporters of the Neptunian and Plutonic theories respectively. Many of the phenomena were most carefully studied, especially in Glen Tilt, where Hutton found the most beautiful illustration of his theory of the igneous origin of the granites, and where Playfair, Webb Seymour, and Macculloch by a series of patient observations contributed so much towards the establishment of the truth of that theory.

The largest and most important of the igneous masses of the Grampians are the great granitic bosses, which give rise to so many varieties of physical feature—from the lofty mountains of the Cairngorm, Beinn Nevis, and Beinn Cruachan groups, to the low, undulating, and sometimes almost level tracts of the Ross of Mull, the Moor of Rannoch, and many districts in Aberdeenshire. Where, through extensive denudation, the lower and deeper portions of these masses are exposed, they are found to be composed of an almost uniform mass of typical granite, such as is so well seen in the Ross of Mull; but where, on the other hand, they rise into lofty peaks, the granite is found to become more and more hornblendic, and then to graduate through euritic varieties into a felsite, usually more or less porphyritic in structure (porphyry of authors). The same changes are often found to take place in the characters of the rocks composing these great eruptive masses when we trace them from their central portions towards their outer margins.

The relations which exist between the great granitic masses and the stratified rocks among which they lie have been clearly described by many observers. Whenever we approach such intrusions the prevalent strike and dip of the beds in their neighbourhood appear to be more or less interfered with, and the strata are seen to be frequently affected by sudden disturbance and contortion. Moreover the uniformly metamorphosed Lower Silurian rocks are found in the neighbourhood of all these masses to have undergone further and striking changes, which are of a comparatively local character.

It is evident that these great masses of granitic rock have been forced in a fluid or semifluid condition through the strata among which they lie, and which, in their passage, they have disturbed and altered. This is confirmed by the fact that when we examine the junction of the granite and stratified rocks; we find the former sending off numerous veins into the latter, which veins often include angular fragments of the traversed rock, that have been caught up and enclosed in their substance. Moreover similar fragments, often of large size, but more or less altered on their surfaces and frequently

traversed by granite veins, are found actually imbedded in the granitic masses. And, further, it appears that considerable tracts of stratified rocks, preserving all their usual characters, were actually enveloped by the fluid igneous protrusions; and thus we have often the most complex entanglements of the granitic and stratified rocks. These facts are very clearly exemplified in the fine coast-sections of the Ross of Mull, and more obscurely, owing to the want of sections, at many points in the Grampian Mountains.

But besides these great granitic masses and the veins in immediate connexion with them, the whole district for many miles around bears witness to the igneous activity to which their origin is referred. In all directions smaller masses of granite, syenite-granite, or felsite are found, either forced between, or cutting across the strata; while dykes of similar materials, passing into felstones, are found traversing the surrounding rocks, in all directions and often to great distances from the great central igneous masses. Such veins and dykes usually occur in prodigious numbers near the great granite protrusions, as is so well seen in the passes of Glencoe and Brander; but their frequency diminishes in proportion as we recede from the central intrusive masses.

The smaller intrusive masses and the dykes effect a certain amount of local metamorphism in the rocks which they traverse; but this is far more limited in extent and less striking in character than that produced by the great central granitic masses. Where, however, the stratified rocks are traversed by a complete plexus of dykes, as in Glencoe, the amount of alteration produced by them in rocks through which they pass is often very considerable.

The period at which these intrusions of igneous rocks (which are almost uniformly of acid or felspathic composition) took place we can approximately determine. No one can study the distribution of the various rocks which make up the Lower Silurian strata of the Highlands, now that the true succession of these beds has been so clearly demonstrated by the labours of Sir Roderick Murchison and Professor Geikie, without perceiving that the igneous protrusions were posterior, not only to the deposition of the Lower Silurian rocks, but also to the disturbance and metamorphism by which they have acquired their present characters. This necessary corollary to the main conclusions arrived at concerning the succession of the Lower Silurian strata was clearly recognized by the authors whom I have cited*.

On the other hand, that these granitic protrusions took place prior to the deposition of both the Secondary and Tertiary strata, is sufficiently shown by the fact that no traces of the extensive network of veins and dykes proceeding from them are in any instance found traversing these younger rocks.

Thus it appears certain that the igneous rocks of the Grampian Mountains must be referred to some part of the Newer Palæozoic periods. Pebbles of these granitic rocks are entirely absent from the conglomerates of the Old Red Sandstone, which, however, are

* Quart. Journ. Geol. Soc. vol. xvii. p. 228.

often wholly made up of fragments of Silurian strata. This absence, is very striking when, as sometimes occurs, masses of granite are now exposed in the immediate neighbourhood of the conglomerates; and it affords a strong confirmation of the age which we have assigned to the granites, by showing that at the time when the Old Red conglomerates were formed, the granites were not exposed at the surface.

Now, in the whole of the phenomena presented by the igneous masses of the Grampian Mountains, we have an exact counterpart of those which we have seen are displayed, as the result of subterranean action, in the case of the great Tertiary volcanoes of the Hebrides. In both cases we find great intrusive masses of granite, passing by insensible gradations into syenite-granite and felsite; and these, in rising through the surrounding strata, violently disturb and greatly metamorphose them. With the great bosses of igneous rock are evidently connected, in both cases, those smaller masses and dykes of similar materials, which traverse the surrounding rocks, producing in them degrees of disturbance and metamorphism proportional to their bulk.

We have already seen that both north and south of the Grampian Mountains we have proofs of the former existence of extensive plateaux composed of lavas, for the most part of a felspathic character. Unmistakable evidence, both stratigraphical and palæontological, and of totally independent character in either case, has led us to the conclusion that the subaerial felstone and porphyrite lavas of Lorn, the similar subaqueous lavas of Central Scotland, and the intrusive masses of identical ultimate chemical composition in the Grampians, were all formed during the same geological periods, those constituting the latter part of the Palæozoic epoch. From the relations shown to exist between the granitic rocks and lavas of Tertiary age already described, we are thus led to see that there are strong grounds for the presumption that a connexion between these different igneous rock masses once existed, and that they all form fragments, now isolated from one another by extensive denudation, of the same great series of volcanic outbursts. I shall now proceed to adduce evidence which is, I think, sufficient to convert this strong presumption into almost absolute certainty.

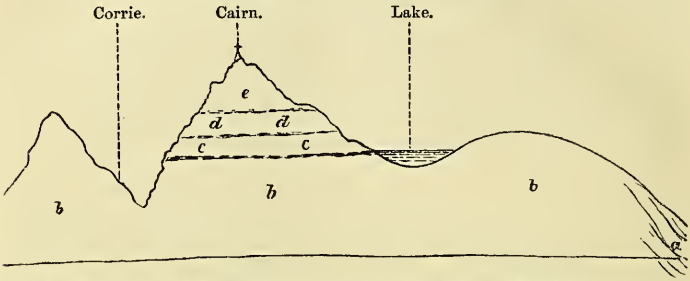
9. *Relations of the Igneous Rocks of Beinn Nevis and Glencoe.*—In spite of the arguments already brought forward in support of the view that the subaqueous lavas of Central Scotland and the subaerial lavas of Lorn originally formed parts of one series of wide-spread plateaux, and that the great igneous masses of the Grampians are the relics of great centres of eruption during the same period, some may be inclined to regard it rather as a bold speculation than as an established scientific conclusion. It is a fortunate circumstance, therefore, that we are able to point to more than one relic of these volcanoes of the Newer Palæozoic period, the study of which is sufficient, I believe, to convince the most sceptical upon the subject.

Amid that broad belt of elevated ground constituting the Grampians, the peak which rises superior to all the rest is—that monarch

among British mountains—Beinn Nevis. The superior elevation of this peak has resulted in the preservation of rocks elsewhere wholly removed by denudation; and the mountain group of which it forms a part is as conspicuous for the value of the evidence which it affords to the geologist, as it is for its great elevation and its strikingly picturesque features. Let us therefore ascend this mountain and study its structure.

Beinn Nevis consists of a well-marked and, to a great extent, isolated group of mountains, having a circumference of about 20 miles

Fig. 11.—*Diagrammatic Section illustrating the Relations of the Rocks forming Beinn Nevis.*



a. Lower Silurian rocks, greatly contorted and metamorphosed at their junction with the granite.
b. Coarse-grained porphyritic granite, with many "contemporaneous veins" graduating into *c.*
c. Fine-grained granite graduating into felsite.
d. Felsite sending off veins into *c.*
e. Felstone lavas and volcanic agglomerates alternating with one another.

and culminating in a peak 4406 feet above the level of the sea (woodcut, fig. 11).

The outskirts of this mountain group are composed of the gneiss, schist, quartzite and limestones of the Lower Silurian, the highly inclined strata of which are seen striking N.E. and S.W., on either side of the great intrusive mass of granite which cuts across them abruptly. From the great central granitic mass there proceed numerous offshoots, sheets, veins and dykes, composed of granite, syenite-granite, felsite, &c., which traverse the stratified rocks in all directions, penetrating between or cutting across their beds.

As we approach the central mass of igneous rocks, the regular dip and strike of the stratified rocks is found to be greatly interfered with, considerable disturbance and contortion being manifested among them. Further, in proximity to the intrusive igneous mass, the already metamorphosed Lower Silurian rocks are found to have undergone still greater alteration; the uniform flaggy masses pass into highly micaceous, chloritic, talcose, hornblendic and actinolitic schists, while the associated limestones become more highly crystalline and intermingled with serpentine.

The great mass of the central mountain-group of Beinn Nevis is

composed of hornblendic granite, passing by insensible gradations into ordinary granite on the one hand, and into syenite granite on the other. The normal character of this rock is that of an aggregate of white orthoclase and oligoclase felspar with colourless quartz and hornblende, the latter being usually in part replaced by varying proportions of lepidomelan; and the whole mass is rendered beautifully porphyritic by the dissemination through it of fine crystals of orthoclase felspar of a pink colour. Locally, however, it exhibits many variations from the typical character. It is traversed, too, in every direction by veins of various size, composed usually of granite of finer grain, of euritic felsite, or of crystallized quartz and felspar. The granitic rocks constitute those great spurs, with sharp summit-ridges and steeply sloping sides, which divide the deep corries that form so striking a feature in the Beinn Nevis group.

Let us now ascend the central peak and examine its structure. Some distance above the well-known lake, which lies in a hollow upon the shoulders of the mountain, a remarkable change is found to take place in the character of the granitic mass; it becomes much finer-grained, and as we still ascend we find the hornblende and mica gradually disappearing, till in the end the rock becomes a finely granular felsite of a pale red colour, and often more or less porphyritic in structure.

The highest portion of the mountain, however, is composed of a mass of rocks of totally different character. Instead of the pale red granites, eurites, and felsites, we find dark-blue, grey, greeenish, and purplish felstones; and associated with these are enormous masses of volcanic agglomerate, composed for the most part of angular fragments of all sizes, of felspathic materials, heaped together in the wildest confusion, and compacted into masses of great solidity and hardness.

The confusion produced by the ever descending fragments which cover the upper slopes of the mountain and constitute such impressive evidence of the potency of atmospheric agencies in the work of denudation, is inimical to a complete study of the relations of the rocks forming the summit of the mountain; but an attentive examination both of these slopes and of the more accessible of the precipices surrounding the corries shows that the felstones form great sheets, sometimes exhibiting a rudely columnar structure, and that between them lie the enormous masses of volcanic agglomerate, the whole being traversed by innumerable felstone dykes.

From the same cause, namely the abundance of *débris* on the higher slopes of the mountain, the relations of the underlying felsites and granite to the great cap composed of felstones and agglomerates is not at first sight very apparent. Careful study, however, shows that the former rocks send off veins into the latter; and the abundance of the fragments of the granitic rocks, above the level at which the lavas and agglomerates commence, shows that these veins are by no means few in number.

With regard both to the felstone lavas and the associated agglomerates, the changes produced by the chemical action that has taken

place in the mass has been very great. But in this, as in so many similar instances, weathering action is found to a great extent undoing the work of metamorphism, and revealing original structures that had been wholly obscured by it; thus many rocks, now of highly crystalline or compact character, are shown to have been originally composed of highly vesicular or scoriaceous materials.

The remarkable characters and relations of the rocks forming Beinn Nevis were not unnaturally the cause of much doubt and difficulty during the infancy of geological science. Almost the only attempt at their explanation hitherto made, consists in the suggestion that masses of "porphyry" had been forced through the midst of an earlier-formed mountain of granite.

But to any one who has studied the Tertiary volcanic rocks of the Hebrides nothing can be clearer than the significance of the features exhibited by Beinn Nevis. Indeed it is evidently but a repetition, on a grander scale, of many a Tertiary mountain like Beinn Uaig in Mull, which we have already described. In both alike we see the evidence that while felspathic lava streams and scoriæ were being erupted at the surface, masses of molten materials of the same composition were intruded below them, and by slow consolidation forming those bosses of felsite which pass by insensible gradations, in their lower and deeper parts, into hornblendic and ordinary granite. That both alike constituted portions of great volcanic piles is, I believe, from the facts adduced in this memoir, placed beyond dispute.

Scarcely less interesting, in their bearing upon the present inquiry, are the phenomena displayed in Glencoe. At the northern end of the celebrated pass we find the Lower Silurian strata undergoing considerable disturbance and great metamorphism; and they are also seen to be traversed by a wonderful plexus of veins, dykes, and intrusive masses composed sometimes of hornblendic granite, but more usually of numerous varieties of red felsite ("porphyry" of authors). The stratified rocks are overlain by great masses of felstone, with some beds of the so-called "brecciated porphyry" (consolidated ash, scoriæ, &c.), which are, however, by no means so abundant here as on Beinn Nevis. These felstones are traversed, like the stratified rocks upon which they rest, by an almost infinite number of veins and dykes, usually composed of felsite; and they have in many cases undergone a certain amount of alteration from heat, similar to that which we have seen taking place in the Tertiary lavas under like conditions, and resulting in the development in them of a peculiar banded structure and splintery fracture.

These felstones occupy the whole of the central parts of the pass, and weather into those striking forms which characterize the scenery of this famous spot. At the southern end of the pass there appear from underneath these altered felstones, the felsites passing into granites, and enclosing masses of often highly altered Lower Silurian strata, which constitute the great intrusive mass of the Black Mount.

Here it is evident that there has escaped destruction by denuda-

tion a portion of the lavas and associated beds which formed the outskirts of one of the great Newer Palæozoic volcanoes—the lavas of Glencoe lying in part on the disturbed and metamorphosed stratified rocks, and in part on the great eruptive masses which have produced that disturbance and metamorphism.

Besides Beinn Nevis and Glencoe there are some other points which exhibit, though in a less striking manner, relics of these doubtless once grandly developed masses of lava and fragmentary materials, which during the Newer Palæozoic periods formed those great volcanic cones of which the granitic masses of the Grampians constituted the central cores, and which rose above vast plateaux of the felspathic lavas that issued from them; of these plateaux only small and outlying fragments have, by a combination of accidents, escaped destruction by denudation. There is one fact which I have not yet noticed, but which is of a sufficiently striking character to arrest the attention of every geological observer; I allude to the very marked similarity in petrological characters between the vestiges of the lava rocks preserved in Beinn Nevis and Glencoe on the one hand, and those which make up the larger areas, as of Lorn and central Scotland on the other.

10. *Physical Features of Northern Scotland during the Newer Palæozoic periods.*—That the different deposits of the Old Red Sandstone were accumulated in lakes, has been suggested by Mr. Godwin-Austen, and supported by a variety of arguments by Prof. Ramsay. The peculiar characters of the deposits of this age in the districts referred to in this paper appear to accord perfectly with this hypothesis.

The conditions which prevailed during the earlier part of the Newer Palæozoic periods would appear to have been as follows:—In what is now the Scottish Highlands an extensive land area existed, with a number of more or less isolated lakes or inland seas. Along the line now occupied by the Grampian Mountains rose a range of great volcanic cones, while numerous intermittent eruptions took place at the bottom of the great sheets of water; the centres of eruption of some, at least, of these have been pointed out by Mr. Maclaren and Prof. Geikie. Thus while great masses of lava, with agglomerates, tuffs, and ashes, were accumulating round the great volcanoes, other enormous deposits were simultaneously formed, consisting of alternations of similar lavas with stratified rocks—the latter being composed in part of the detritus of these lavas, in part of fragmentary eruptive materials which fell into the lakes, and in part of the materials derived from the older rocks which formed their shores. A similar series of operations went on during the next succeeding period, that of the Calciferous Sandstone, though, in consequence of physical changes, lacustrine were exchanged for estuarine and terrestrial conditions.

During the whole of these periods much local subsidence must have taken place, to permit of the accumulation of such enormous thicknesses of rocks; and the resulting disturbances led to the production of those local unconformities which have been noticed

by Prof. Geikie and other authors. These unconformities do not appear, however, to have the same significance which we naturally attribute to phenomena of the same kind when exhibited by rocks which have been formed under less violent conditions.

We have seen that, during the later portions of the Tertiary epoch, the eruptions from the great centres of volcanic activity were succeeded by a series of sporadic eruptions, resulting in the formation of numerous small cones or "puys;" and in this we find a close analogy with what has taken place in the case of many modern volcanoes. The great volcanoes of the Grampians, which were in activity during the Newer Palæozoic periods, also appear on their extinction to have been succeeded by the outburst of numerous "puys." "The area of the Lothians and Fife," says Prof. Geikie, "appears to have been dotted over with innumerable volcanic vents;" and these sporadic eruptions seem to have continued during a great part of the Carboniferous and Permian periods. These latest eruptions of the Palæozoic epoch consisted of materials of more or less basic character; and the wide-spreading sheets of melaphyre and similar rocks connected with them, and intruded between the older strata, have given rise to those numerous "crags" which, often crowned by old castles, form such a striking feature in Lowland scenery. The most familiar type of these later palæozoic "puys" is the well-known Arthur's Seat, near Edinburgh, the origin of which has been so well illustrated by Maclaren, Edward Forbes, and Prof. Geikie; but innumerable other beautiful examples of the same kind occur, some of which are described in the publications of the Geological Survey.

IV. *Conclusion.*

1. *Comparison of the two Great Periods of Volcanic Activity in Scotland.*—From the facts described in the present paper it appears that the British archipelago, in common with the surrounding districts, has been the theatre at two distinct periods, since the deposition of the Silurian rocks, of exhibitions of volcanic phenomena upon the very grandest scale. The first of these epochs of violent igneous activity appears to have lasted from the commencement of the Old-Red-Sandstone period down to the close of the Palæozoic era; the second, during nearly the whole of the Tertiary epoch. The interval between these two grand displays of igneous forces, namely that during which the Mesozoic strata were deposited, appears to have been one of comparative, perhaps of complete, quiescence of volcanic action. Bearing in mind the arguments of Mr. Darwin in support of "the identity of the force which elevates continents with that which occasions volcanic outbursts," it is not a little interesting to find that the periods of maximum volcanic activity, namely the Old-Red-Sandstone and the Miocene, appear to have coincided with those during which (as hown from various considerations by Professor Ramsay) a great extent of continental land prevailed in the same areas.

A comparison of the products of the volcanoes of the Newer Palæozoic and Tertiary periods respectively, leads us to the following conclusions.

During both of these periods of igneous activity, as in the case of volcanic outbursts of more recent times, the extrusion of lavas of highly felspathic composition has, as a general rule, preceded those of the basaltic varieties.

But, while in the later of these epochs, the Tertiary, we have a period characterized by the ejection of lavas and the intrusion of subterranean masses of highly silicic composition, followed after a long interval by the outburst from the same vents of highly basic igneous rocks, in the earlier of the two epochs (the Newer Palæozoic) we witness, apparently, a gradual transition during the enormous periods through which the eruptions continued, from rocks of a moderately acid to others of a moderately basic character.

The last efforts of volcanic activity in each of these epochs, as in the case of many, if not all, recent exhibitions of volcanic phenomena, have been of a sporadic character, and have resulted in the formation of numerous, but comparatively small, volcanic cones or "puys."

At the earlier epoch the range of great volcanoes was thrown up along a line ranging N.E. and S.W., coincident with the direction of the subterranean forces which, both long before and subsequent to their upheaval, appear to have determined the elevations, foldings, and great fractures of the rocks of the district. But at the later epoch the volcanoes were thrown up along quite a different line, one ranging N. and S.; and there is evidence that at the close of the Mesozoic era new axes of upheaval were originated, differing in direction from those which had prevailed during the whole of the periods from the Silurian to the Cretaceous.

But to the consideration of these general conclusions concerning the subterranean forces, and their influence in determining the characters and position of the strata, I shall have to return in the concluding division of this memoir.

2. *Influence of Volcanic Action in determining the Characters and Relations of the Secondary Rocks of Scotland.*—The importance of a clear conception of the history of the two great periods of volcanic activity, which respectively preceded and followed the deposition of the Mesozoic strata, to a complete understanding of the nature and significance of the features presented to us by the latter, is shown by the following considerations.

(1) The main features of the physical geography of the area in which the Secondary rocks which we are studying were deposited, were to a very great extent originated by that grand exhibition of volcanic activity which had only just come to a close when the formation of the latter commenced. Hence this pre-Mesozoic volcanic action had much to do in determining the nature of the rocks which supplied the materials of the Secondary sediments, and also the conditions under which they were accumulated.

(2) Constituting, as we have seen it did, a period of rest

between two epochs of the most violent volcanic activity, the Mesozoic era may well be supposed to have been characterized by the subdued efforts of those imprisoned forces which were unequal to the task of opening "safety-valves" for their violence at the surface. I shall show in the sequel that many of the anomalous characters of the Secondary rocks in this district can only be explained on the supposition that during the period of their deposition the area was subject to frequent and great oscillations of level.

(3) It is to the overwhelming masses of matter poured out by the Tertiary volcanoes that the preservation even of such small vestiges of the Secondary rocks as remain to us is wholly due. In the case of each of the patches of these strata which we are called upon to study on the west coast of Scotland, the positions and relations of its beds, and the nature and extent of its metamorphism, are the result of that complicated series of volcanic phenomena which followed their deposition.

3. *The "Geological Record" in the Scottish Highlands.*—The purposes which the Alps have served to continental geologists, have been to a great extent fulfilled in the case of British observers by the Scottish Highlands; and in either of these districts the materials for the solution of some of the most important problems of physical geology have been not unsuccessfully sought for. It was not unnatural that, in the case of both these mountain-groups, the greatly altered and highly crystalline character of the rocks which compose them should have been looked upon by the older geologists as proofs of their great antiquity. But the discovery of fossils in some of the less-altered portions of the Alpine rocks has quite revolutionized the views of geologists upon the subject of their age; and, similarly, the results of recent researches in the Scottish Highlands enable us to refer their great crystalline masses to well-known, and in some cases very recent, geological periods.

Should any one still cling to the old view that highly crystalline characters in rocks may be regarded as a criterion of antiquity, I would point to the Cuchullin Hills of Skye, which have been regarded as of Laurentian age, but which, from the clearest evidence, we have shown to belong to the Miocene period.

The early maps of the Scottish Highlands were of necessity purely *mineralogical.* The first attempt at the production of a *geological* map, that is of one in which the classification of the rocks adopted is based upon the periods of their formation, is the Sketch Map of Murchison and Geikie, published in 1861. The production of this was rendered possible by Peach's important discovery of Lower Silurian fossils in the limestone of Durness. We are now, however, in a position to show that the rocks of the Highlands, far from being of great and unknown antiquity, include representatives of a great variety of geological periods. The rocks of Lower Silurian age are of great thickness, and cover a vast extent of country; and beneath them we find two older series of strata which may, possibly, represent the Cambrian and the Laurentian. Of the existence of Upper Silurian rocks in the Highlands we have as yet no certain evidence; but the

Old Red Sandstone is admirably represented, in all its divisions, both by sedimentary and igneous products; while the Carboniferous and Permian (?) also find representatives in rocks of the latter class. As I shall show in the present memoir, we have fragmentary but almost consecutive examples of all the Mesozoic formations, from the Trias to the highest rocks of the Cretaceous series. In the Tertiary epoch we have the felspathic igneous rocks representing the Eocene period, the basaltic rocks, the Miocene, and the smaller scattered eruptions of the "puys" the Pliocene; while of the Pleistocene period the interesting glacial deposits of the Highlands supply us with a sufficient record. Thus we arrive at a basis for the construction of a true geological map of the Scottish Highlands; but the actual performance of this task is one which will demand a vast expenditure of time and effort.

4. *Light thrown on some problems of Physical Geology by the Volcanic Rocks of the Highlands.*—The admirable labours of those pioneers of Scottish geology, Hutton, Playfair, Webb Seymour, James Hall, and Macculloch, have clearly demonstrated the relations which exist between the granitic and the associated strata of the Highlands. On the other hand the researches of Scrope among the extinct volcanoes of Central France, supplemented as these have been by the observations of Darwin, Lyell, and a host of other geologists, in the most widely scattered districts, have thrown much light upon the structure of modern volcanoes and upon the nature and succession of the phenomena which accompany their formation. In the rocks of the Hebrides we find the means of connecting these two series of observations, and thus of arriving at a complete theory of the action of the igneous forces operating under different conditions.

The characteristics of *Stigmariæ* and *Sigillariæ* respectively were known to palæontologists long before the discovery of a section in the Coal-measures enabled them to be identified, in their true relations, as the roots and trunks of the same plant. Similarly physical geologists have separately studied the features of Volcanic and Plutonic rocks, which the wonderful sections of the Hebrides now warrant us in affirming to have the closest connexion—the great intrusive masses being, as it were, the roots of a tree of which the stem, branches, and leaves are represented by the dykes, lava streams, and cinder piles of great volcanic cones.

From the active volcanoes of Etna, Vesuvius, and Skaptar Jökul, the step to the ruined piles of the Mont Dore and the Cantal is an easy one: and with these last we have but little difficulty in perceiving the parallelism of the phenomena displayed by the rocks in the central mountain-group of Mull. From the condition of the volcanic rocks in Mull to that in Skye the transition is obvious, and from the latter to Beinn Nevis, and thence to the granitic bosses of Cairngorm, the Moor of Rannoch, and the Ross of Mull, can easily be made; nor will any difficulty be experienced in passing from these latter to the wide-spreading tracts of granite, such as that of Leinster.

Circumscribed though the observations of the geologist necessarily are, within the infinitesimal periods of human chronology, he may nevertheless learn to triumph over the painful limitations of time by availing himself of the opportunity which he has of studying the same series of operations at various stages of its progress, as presented in different examples. As was so well expressed by Playfair, "It is true we do not see the successive steps of this progress exemplified in the states of the same individual rock, but we see them clearly in different individuals; and the conviction thus produced, when the phenomena are sufficiently multiplied and varied, is as irresistible as if we saw the changes actually effected in the moment of observation"*.

To this mode of reasoning the geologist is continually compelled to resort. If, as I believe, it is demonstrated that in wide-spread intrusive masses of granite and gabbro or serpentinous rocks—in the more or less isolated mountain-groups of granitic and doleritic rocks—in the great volcanic mountains in varying stages of decay and destruction by denudation—and in the long lines of parasitical cones which surround them, we witness but different portions of the same grand series of phenomena, then the geologist is enabled to picture to himself the characteristics and results of volcanic activity in all its developments and under all its phases.

Thus he is led to the conclusion that the distinction between Plutonic, Trappean, and Volcanic rocks, convenient though it may be in practice, is a purely artificial one, and that the whole of these must be regarded as the products of the same igneous forces when operating under different conditions. While, on the one hand, we are led to conclude that great tracts of granite, like that of Leinster, may once have been surmounted by vast volcanic piles, we cannot, on the other hand, doubt that the subaerial volcanic phenomena of Iceland, Sicily, and the Andes are accompanied by innumerable igneous injections in subjacent strata and the formation of masses of granite, syenite, diorite, and gabbro at great depths beneath them.

EXPLANATION OF PLATES XXII. & XXIII.

In these Plates an attempt has been made to illustrate the relations of the great masses of volcanic rocks in the Hebrides to one another, and to the sedimentary deposits which they have been the means of preserving.

The sketch map on Plate XXII. is an attempt to exhibit the relations of the outcrops of the great intrusive bosses, sheets, and dykes of igneous rock to the lavas, agglomerates, and older strata in the island of Mull; but this, owing to the small scale employed, could only be accomplished in a somewhat diagrammatic manner. To display the complicated interlacings of the almost innumerable igneous intrusions of the district would require maps of great accuracy on the largest scale, and even then could only be attempted after a very detailed and minute survey of the area. Unfortunately the Inner Hebrides have not yet been surveyed by the Ordnance Department; and, although the coast-lines are well laid down on the Admiralty Charts, the geologist meets with almost

* Illustrations of the Huttonian Theory, p. 101.

insuperable difficulties in attempting to record and correlate his observations on the interior portions of the larger islands, from the want of even tolerably accurate maps.

Although I have endeavoured to make the best possible use of all the materials which were available as a basis for my study of the position and relations of the rocks of Mull, yet nothing more could be attempted, in such a sketch map as the present, than to convey a general idea of the structure of the island. It must be remembered, in examining this map, that the forms of the outcrops of the ramifying masses of igneous rock, as there laid down, are in part determined by the surface-contours in these highly mountainous districts. Thus the outcrop of a mass of rock filling a *rectilinear* fissure, when exhibited on a mountain-side, forms a *curved* line. It is especially necessary to bear this fact in mind in seeking to realize from the map the actual relations of the great solid rock masses. Of course in a map on so small a scale, the *size* of the dykes and sheets has had to be enormously exaggerated, while only the most imperfect idea is conveyed of their vast numbers and complicated relations.

By employing strongly contrasted colours for the two great classes of igneous rock, I have endeavoured to make their relations to one another as clear as possible; while by varying the depth of tint in each case I have sought to illustrate the gradations from coarsely crystalline to granular, compact, and vitreous structures, in rocks of the same ultimate chemical composition. In the scale of colours on the map I have employed the same petrological nomenclature as is used in the memoir; it must be remembered, however, that I have been compelled to use some terms in a restricted and, to a certain extent, conventional manner—as, for instance, in applying the name "felsite" to rocks of granular and "felstone" to those of compact texture. The index of colours on Plate XXII. serves also for the sections on Plate XXIII. On the latter, however, an additional tint (pale red dotted with black) has been employed in fig. 5 for the Cambrian, which does not occur in the map.

In Plate XXIII. all the sections are constructed, as far as possible, on a true scale, the proportions, both vertical and horizontal, being the same in each instance. But this scale is in each section perfectly independent of that of the others; consequently the sections bear no relation to one another.

In the section across the island of Mull (fig. 1) a dotted line is added to show the least possible elevation of the volcano before it had undergone central subsidence and extensive denudation. The asterisks show the difference between the original and the present positions of what is now the summit of Beinn More, as explained on page 259.

The publication of the general Map of the Western Isles is postponed till the appearance of the next paper of the series, as it will serve at the same time to illustrate the relations of the volcanic rocks to one another and the positions of the scattered fragments of sedimentary deposits, from which the history of the Mesozoic periods in this district has to be reconstructed.

Discussion.

Mr. Campbell thanked the author for having taught him so much concerning the country in which he had been born and bred, and invited him to inspect models which are described in 'Frost and Fire.'

Mr. D. Forbes was gratified to find the subject of the igneous rocks of Britain taken up in so able a manner, and the subject not left entirely to continental geologists. The author was fortunate in the fact that he had occupied the same ground as that which had already been explored by Prof. Zirkel, whose work had been thus supplemented. He agreed with the author in regarding Volcanic and Plutonic rocks, from granite down to the most recent lavas, as

of one and the same origin. He suggested a doubt whether the older granites belonged to so recent a period as that assigned to them by the author.

Prof. Maskelyne considered that this paper would go far towards settling the question between one half of the petrologists of the present time and the other half. He accepted the author's view as to the Tertiary origin of the granite, inconsistent though it was with the view of the age of granite maintained by the school of Richthofen. This paper exemplified the necessity of combining the observations of the geologist in the field with those of the mineralogist in his laboratory.

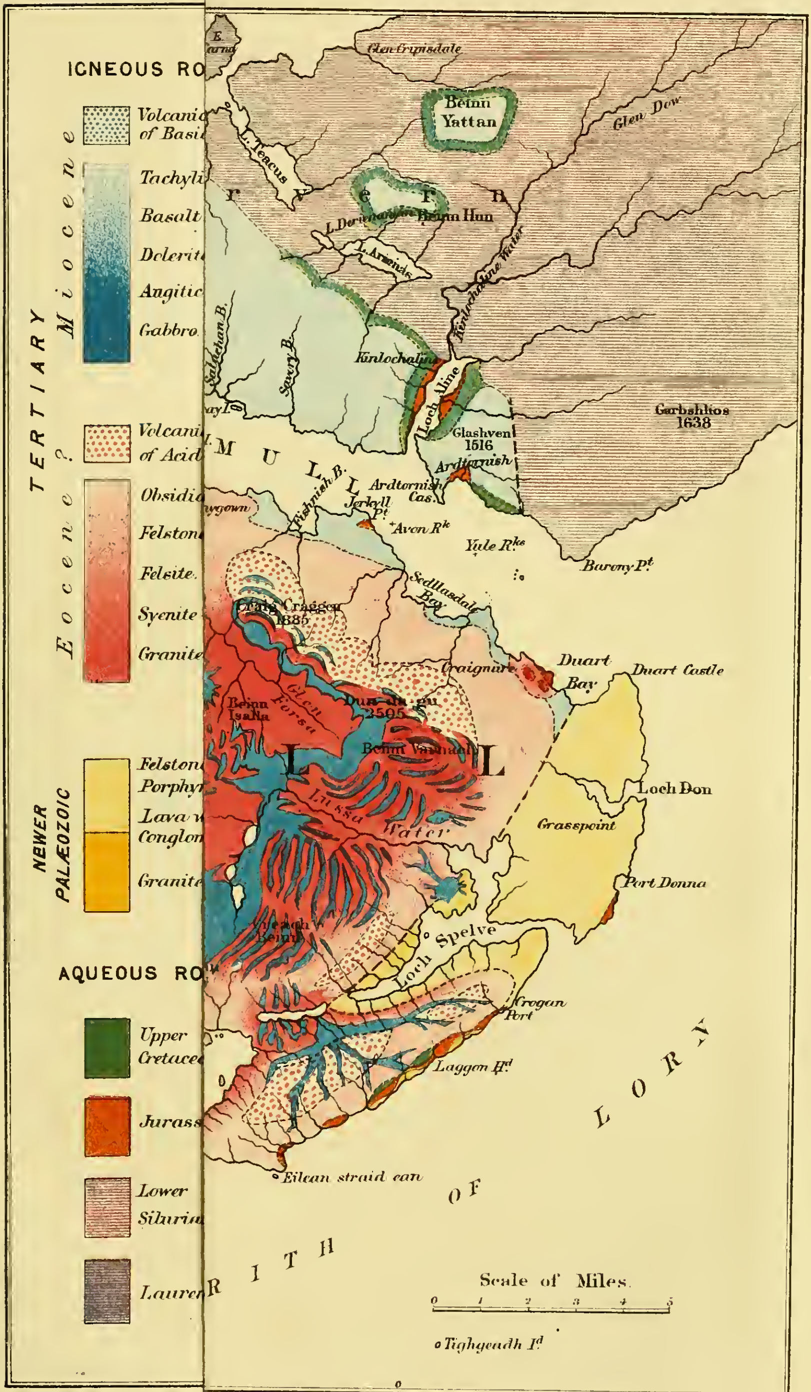
Mr. Seeley remarked on the importance of this paper as furnishing lines of departure for investigating the early physical history of the earth. He had ascertained that the old lines of volcanic activity corresponded with the agonic lines of magnetism; and the paper afforded data which would assist in drawing conclusions as to the changes in the position of the earth's axis by a comparison of these lines with those of the magnetic currents.

Mr. W. W. Smyth congratulated himself on again hearing of intrusive granitic dykes such as recalled the earlier days of the Society, and tended to dispel some accepted ideas as to metamorphism. He adduced the recent deposits of Etna and Vesuvius in illustration of the specimens exhibited by the author.

Mr. Blanford suggested that there might be in this case only one form of the existence of granite. When the gradual passage from schists into granite could be traced, there could be little doubt of its origin; and even in its eruptive form the granite might be only the result of a very complete metamorphism. He agreed with the author as to the probability of the great horizontal outflows of basalt being subaerial, and not subaqueous, and instanced analogous examples in India.

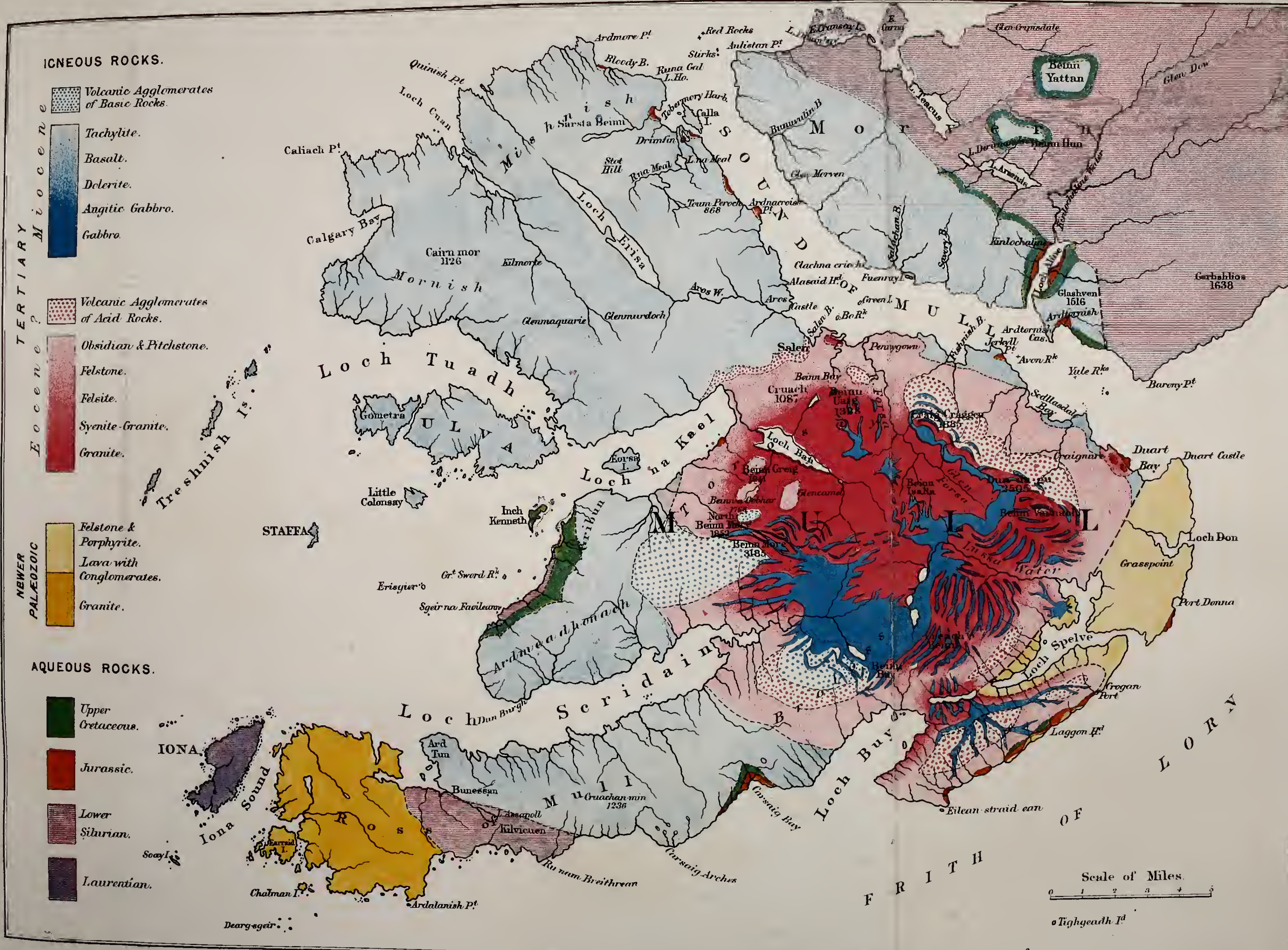
Mr. Tiddeman, referring to the great length of time alluded to by the author as represented in the volcanic rocks of Scotland, wished to call attention to the rocks in the neighbourhood of Seuir-na-Gillean in Skye, which consisted partly of basaltic lavas of Miocene age. These appeared to be tilted by the syenite of Marscou &c.; and upon both rested unconformably a great thickness of hypersthene. But furthermore, the base of this latest rock appeared to be thrown down by a fault with a displacement of some thousands of feet.

Mr. Judd, though admitting there were two sides to the question as to the origin of granite, could not regard intrusive masses of granite passing through rocks of different mineral constitution as the metamorphosed representatives of each. He briefly replied to the other points raised in the discussion.



OF MULL.

Mintern Bros lith.



SKETCH MAP ILLUSTRATING THE STRUCTURE OF THE VOLCANO OF MULL.

Mintern Bros lith.

OUP OF MULL.

CKS IN THE ISLANDS OF

Fig. 1.

SECTION THROUGH THE CENTRAL MOUNTAIN GROUP OF MULL.

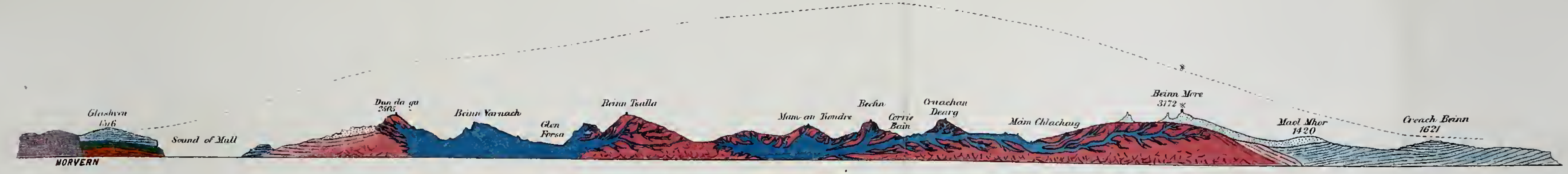


Fig. 2.

BEINN GREIG.

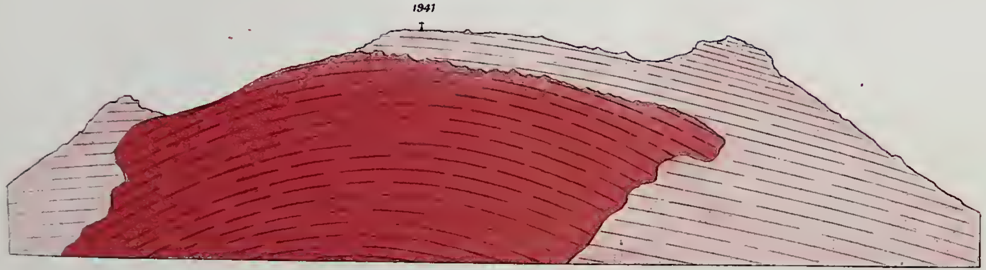


Fig. 3.

CRAIG CRAGGEN.

Fig. 4.

BEINN MORE.

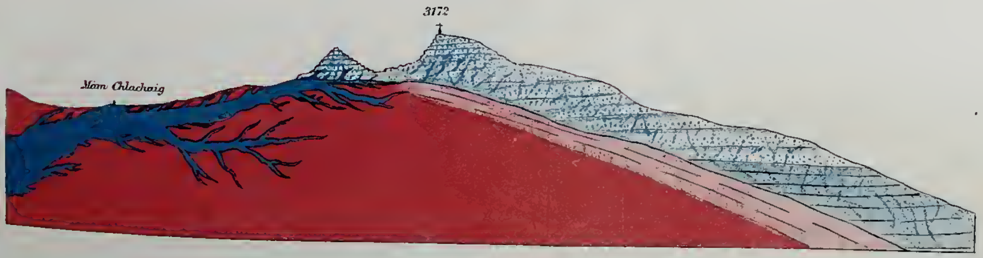


Fig. 5.

SECTION ACROSS RUM.

SECTIONS ILLUSTRATING THE RELATIONS OF THE VOLCANIC ROCKS IN THE ISLANDS OF MULL AND RUM.

Mintern Bros. lith.

24. Note *on the* Occurrence *of* Sapphires *and* Rubies in sitû *with* Corundum, *at the* Culsagee Corundum-mine, Macon County, North Carolina. By Colonel C. W. Jenks. (Read February 25, 1874.)

(Communicated by David Forbes, Esq., F.R.S., F.G.S.)

The oriental ruby and sapphire are, mineralogically considered, merely coloured crystals of corundum, which mineral species has been shown by chemical analysis to consist of the earth alumina in a crystallized state and nearly pure condition. Where these gems have been met with, they appear almost always, if not invariably, to have been discovered in the beds of rivers as waterworn pebbles; and although the existence of corundum in small quantities in granular limestone in Asia Minor and the United States has long been known, any thing like a deposit of this mineral *in sitû*, sufficiently abundant for commercial exploration, appears to have been altogether unknown, until the author's attention was directed to the occurrence of numerous fragments of corundum on the surface and in the river-beds of Macon County, North Carolina, which encouraged him to make a minute examination of this district, and resulted in the discovery, in the summer of 1871, of the deposits of corundum now known as the Culsagee Corundum Mine.

The locality of this mine is a hill, situated about nine miles east of Franklin, the principal town of Macon County, the summit of which is some 400 feet above the valley and about 2500 feet above the level of the sea; geologically it is a boss of serpentine protruded through the surrounding granite.

In the bed of the river, which runs past the south side of this hill, now commonly known as Corundum Hill, numerous waterworn pebbles of corundum, often of large size, were met with, along with small fragments of rubies and sapphires; and subsequent explorations revealed the existence of some fine nearly parallel veins containing corundum, cropping out for a length of about a mile, along the steep side of this hill in a north-east and south-west direction.

These veins all dip to the south-east, at an angle of about 45°, and, although generally only a few inches across at the surface, widen out as they descend into the body of the hill. In the deepest working, now 75 feet, the vein is seen to be 10 feet thick. The veins themselves consist of a mass of chlorite, jefferisite, and corundum, the latter forming from about a third to one half of the entire mass, and occurring as more or less well-developed crystals imbedded in the other minerals. Along with these the following mineral species were found in minor quantity:—chrysolite, anthophyllite, margarite, damourite, felspar, talc, sapphire, ruby, spinel, zircon, hornblende, staurolite, diaspore, black tourmaline, chalcedony, quartz, chromoferrite, magnetite, and two new silicates to which Professor Genth has given the names of kerrite and maconite.